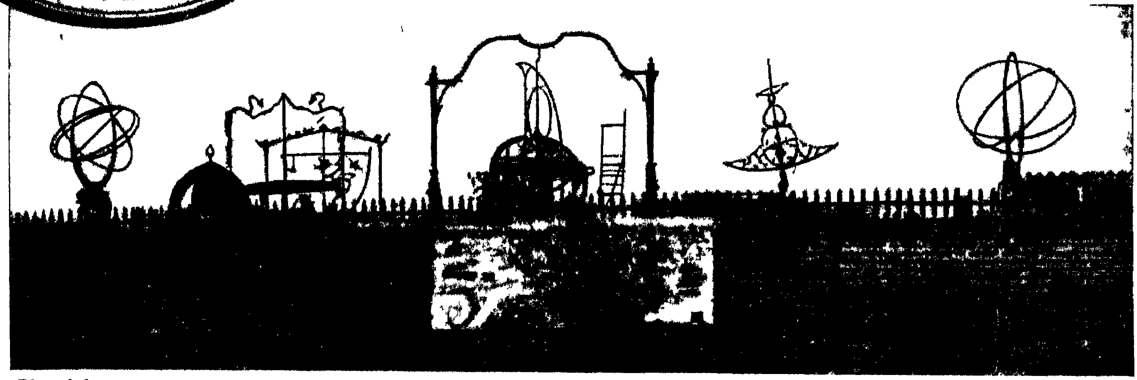


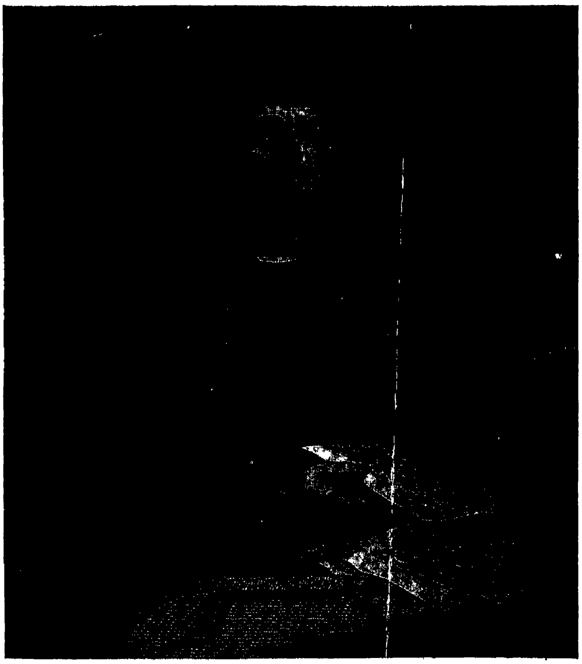
Photo by] [E N A

THE OLD OBSERVATORY AT PEKING
Viewed from the Walls of the Tartar City

Ancient peoples found that a practical acquaintance with the elements of Astronomy was indispensable to the conduct of human life Having no clocks they regarded the face of the Sky Egyptians, Babylonians, and Greeks studied the stars thousands of years ago The Chinese were past-masters in the art of reading the signs of the Heavens Kublai Khan, Emperor of China in 1216, greatly patronised the study of Astronomy He built an Observatory at Peking which he equipped with many important astronomical instruments The Chinese anticipated by at least three centuries some of the most celebrated inventions of Western astronomers

Introduction.

THE majesty of Nature has attracted man from the earliest times Poets, scientists and philosophers have found their deepest inspiration in the composite system which Nature displays The poet sings her beauty the scientist divines her secrets the philosopher proclaims her lessons Indeed, she is the fountain-head of all civilisation Mankind could never have progressed to the extent that it has done were it not for the generous amplitude of Nature in sustaining the physical, mental and moral development of the human race



NICHOLAS COPERNICUS
(1473—1543)

Modern Astronomical Science owes much to Copernicus The question "Does the Earth move ?" he set himself to answer He taught the principle of the Earth's revolution round the Sun—a principle which was later developed by Kepler, Newton, and other celebrated astronomers

In this work a novel departure has been made from the traditional method of studying Nature in the most fascinating of her aspects Its aim is to present in a clear and intelligible manner the present state of our knowledge of the heavens The science of Astronomy has developed from a few scattered observations of the heavenly bodies to be one of very great dimensions, full of complicated technicalities and mathematical formulæ It is no wonder that to "the man in the street" it has hitherto remained an impenetrable fortress, fit only for specialists to enter Up till the present day no attempt has been made on the scale here presented to set before the ordinary man a clear-cut and at the same time comprehensive exposition of the subject in a way that will

not only hold his in-
enthusiasm for a study
tarried in making
Mankind in general has
of Astronomy, the
stars in the heavens
to purify and elevate
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Sciences" possesses in
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In this venture the
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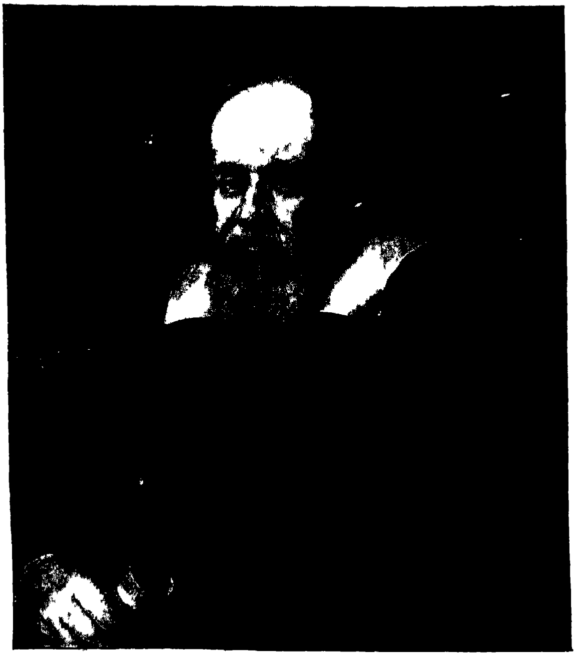


GALILEO
(1564—1642)
Galileo's "glazed optic tube" was the forerunner of the modern telescope The instrument was not actually invented by him, but he was the first to apply it to the systematic study of the Heavens The discoveries he made with it greatly strengthened the Copernican view of the Solar System

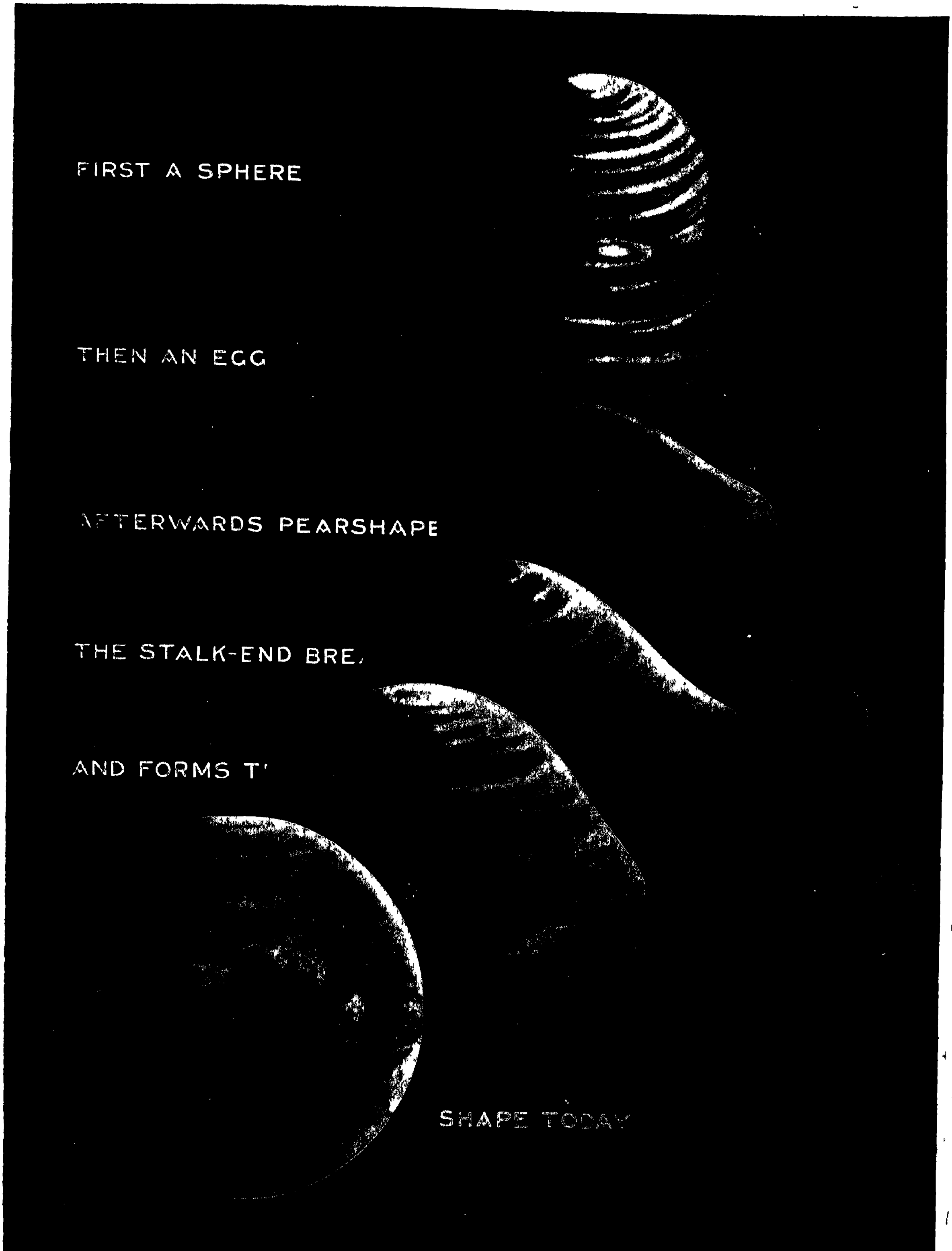
terest, but fire his
which the world has
accessible to him
but a very vague idea
science of the glittering
Nothing is so calculated
the mind of man as
"The Queen of all the
every thread of her
mystery and delicacy
the vast extent of the
reigns Once having
one—and the long line
disciples is a living
pelling attraction—
resist paying her the
homage which it is
bestow

co-operation has been
granted of some of our
mers The benefit of
their accumulated
phenomena places the
of gratitude which is
The chapters under
and subsequent parts
of the work have been specially written by the ablest authorities on the subject for the sole purpose of spreading a knowledge of Astronomy into every homestead and village, town, city and country of the world Of its kind it is the first published with an appeal so universal In addition, the resources of modern telescopic, photographic and spectroscopic knowledge have been utilised in

From the painting] [*By J V Robert Henry*

GALILEO BEFORE THE PAPAL TRIBUNAL

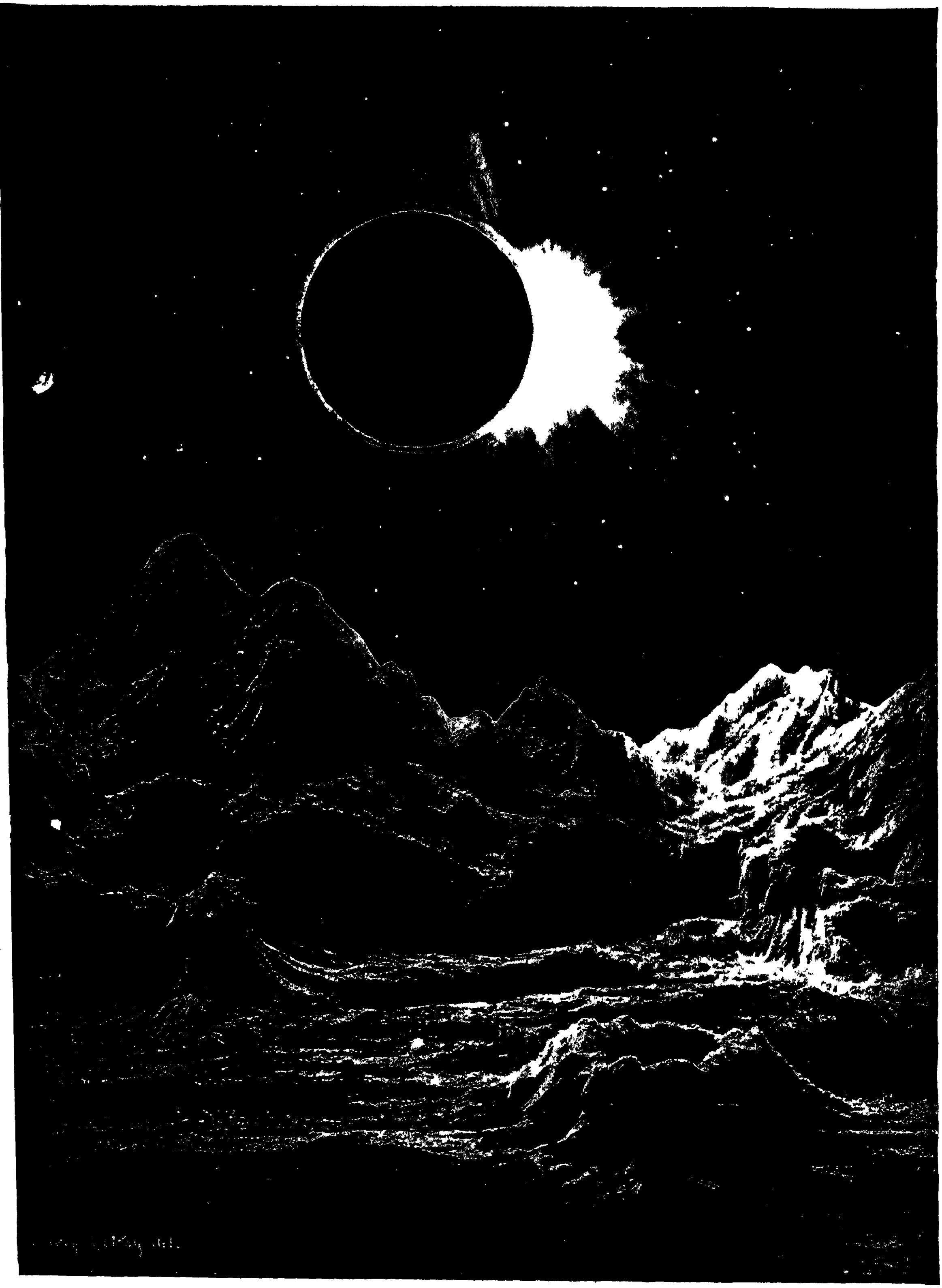
Galileo Galilei (1564–1642) was a mathematician and astronomer and accepted the Copernican theory His lectures at Padua attracted students from all parts of Europe, but his new ideas provoked ecclesiastical censure He was summoned before a papal tribunal in 1632 and condemned to abjure his scientific creed



By permission of] [*L E A*

A THEORY OF THE MOON'S FORMATION

The problem of the Moon's origin has always had a curious fascination for astronomers It is highly probable that the Earth and the Moon were once combined in one and the same body This body would cool, and, as it contracted, its rate of rotation would correspondingly increase until the Moon was thrown into space The tides would act as a drag on the spinning of the Earth and this loss of energy would be transferred to the Moon, which was set whirling round our Globe at an ever-increasing distance. This retreat from the Earth is even now going on

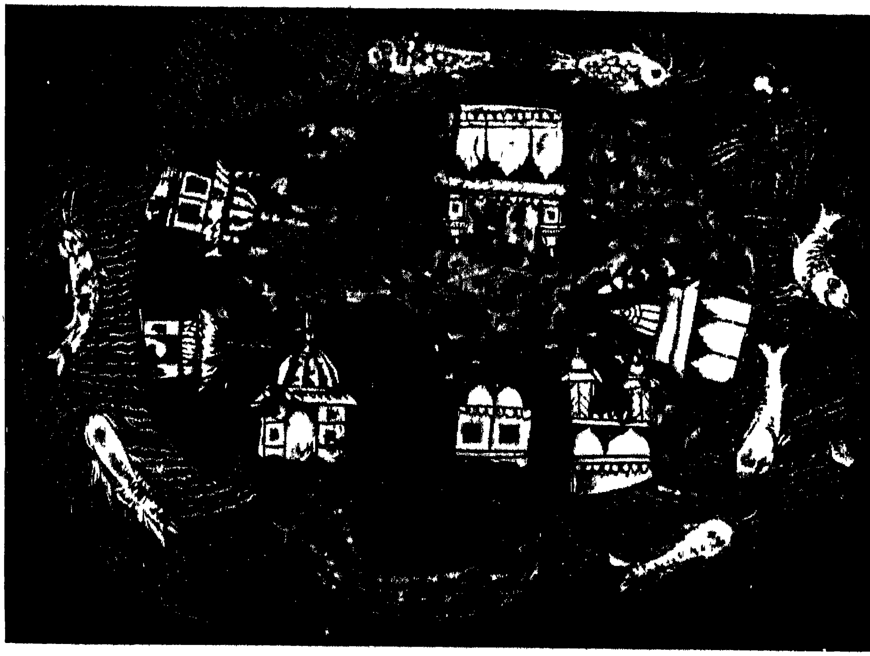


AN ECLIPSE OF THE SUN AS VIEWED FROM THE MOON

When we, on the Earth, see the Moon eclipsed we are watching the effect of our own shadow thrown out into space by the Sun An observer on the Moon would at such a time see the dark body of the Earth passing between himself and the Sun, thus cutting off its light The atmosphere of the Earth would appear as a bright reddish ring, lit up from behind by the Sun

the endeavour to render it a complete descriptive and illustrated narrative of the glorious achievements of astronomical research

On a starry night we gaze heavenwards and view the wide expanse of sky we linger in silent contemplation of the immensity of the scene which stretches infinitely above us What emotions rush uppermost in our souls! We are filled first with wonder at it all then the impulse to



THE EARTH AS A DISC FLOATING IN WATER

So far back as 550 B C the philosopher Pythagoras and his pupils spread the teaching that the Earth was not a disc surrounded by water, as had previously been believed, but a globe floating freely in space Mankind, however, had not yet discerned the great truth that the Earth turned on its own axis

know its why and wherefore is succeeded by a feeling of admiration and reverence for the work which the hand of a Supreme Master has fashioned At each stage in our view the questions arise How and Why? Whence and Whither? "There are two things," says Immanuel Kant, "that ever fill me with new and growing admiration, the moral law within me and the starry heavens above me" The search after truth, whether it be moral truth or scientific truth, bears its own fruits and brings its own discoveries In this glorious adventure man is sustained in the depths of despair by the hope of tasting some-

A MEDIÆVAL ASTRONOMER IN HIS STUDY

There was nothing as good as a modern spy-glass at the disposal of the ancient astronomer Observations of celestial phenomena were made with the naked eye alone, and whatever instruments were in use to assist particular investigations were quite unfitted for precise observations But the foundation of the marvellous structure of astronomical science was laid by these ancient spade workers

thing of its richness Is there conceivable, midst the welter of human strivings, a finer quest and a more ennobling study than that which the science of Astronomy provides ?

Prehistoric man studied the heavens as an indispensable condition of daily life The stars were the almanacs of uncivilised peoples Partly by virtue of its practical necessity it came about that Astronomy was the first-born of all the sciences The stars were studied by the Chinese thousands of years ago the Egyptians, Babylonians, Greeks, in turn attempted to solve the riddle of the Universe Pythagoras taught his pupils that the Earth was a globe and not a disc surrounded by water At so early a date in the development of the science as 134 B C Hipparchus compiled a catalogue of 1,080

SIR ISAAC NEWTON
(1642—1726)

From his earliest days Sir Isaac Newton was engaged in all kinds of mechanical operations, constructing with rude tools windmills, water clocks, sun dials, etc He is famed for his epoch-making discovery of the Law of Gravitation This principle —which he is popularly supposed to have deduced from the fall of an apple from a tree—he extended to the heavenly bodies, which he saw were kept revolving in the sky as a result of the self-same force He discovered the composite nature of white light and introduced improvements in the construction of telescopes

stars The "Almagest" of Ptolemy was based on the doctrine of a stationary Earth, around which the Sun and Moon and the planets revolved as subsidiary and attendant bodies Before the invention of the telescope leading up to the giant instruments of our own day and the magnificent discoveries in photography and spectroscopy—the full advantages of which we are reaping for the first time in this work—the naked eye was the sole register of celestial manifestations Speculation largely held the field till the 16th century, when the ingenious but mistaken doctrine of Ptolemy was displaced by the more simple explanations of Copernicus, who taught the principle of the Earth's rotation and revolution But Kepler was the real founder of modern Astronomy, since he developed

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By permission of] [*L E A*

AN IMAGINARY VIEW ON MERCURY, THE SCORCHED-UP WORLD

Mercury is, of all the planets, the nearest to the Sun It forms, with Venus, the Earth and Mars, a group of "terrestrial planets," so called because all resemble our Globe approximately in size and general characteristics It seems to have little, if any, atmosphere—as is proved by its aspect when passing between us and the Sun The intense heat of the latter must render life, as we know it, impossible on Mercury

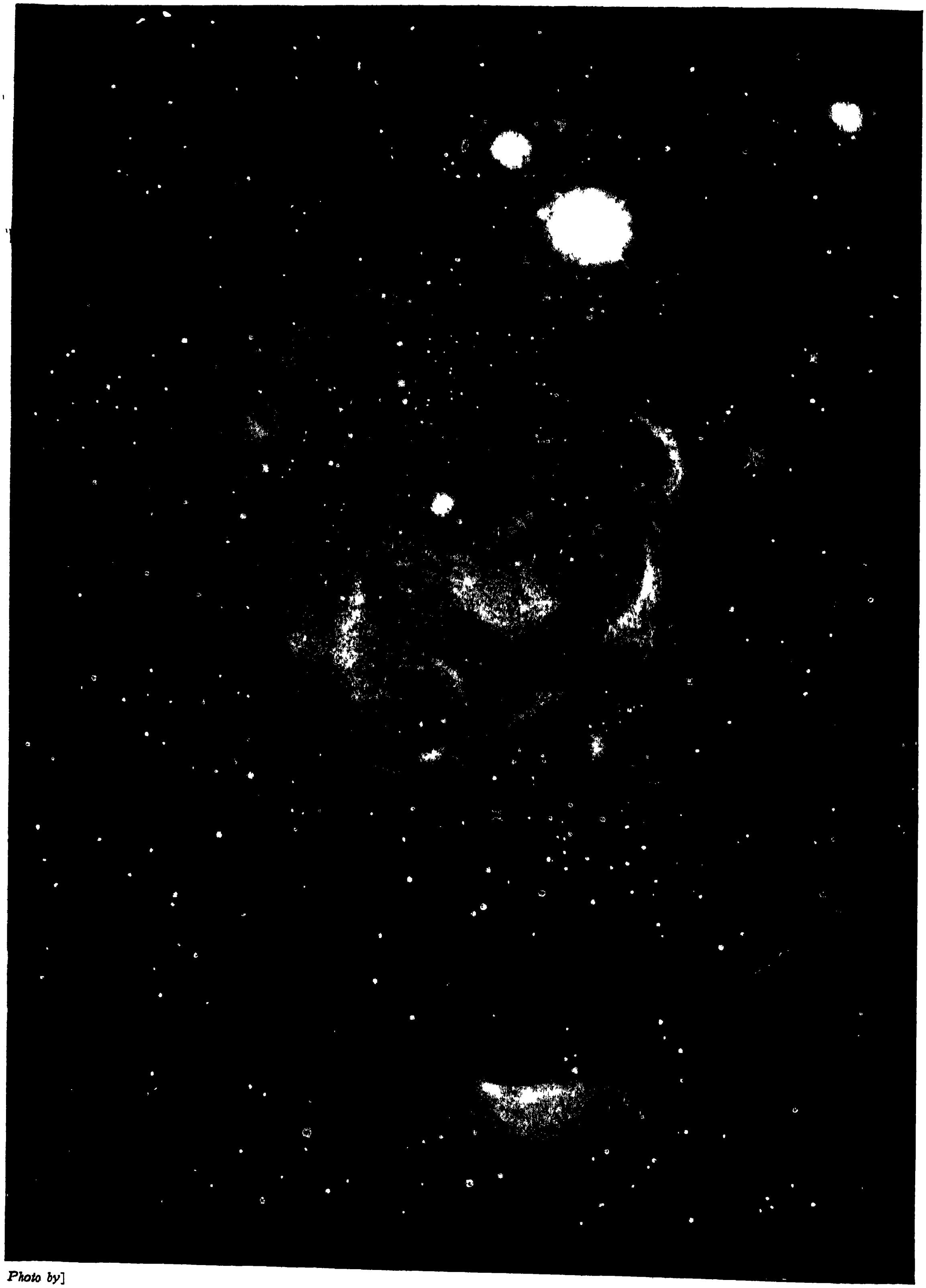


Photo by] [*The Yerkes Observatory*

THE GREAT NEBULA IN THE CONSTELLATION OF ORION

This great mass of hazy greenish light is one of the most wonderful objects in the Heavens It is composed of at least three different gases, one of which, though common in the Heavens, is unknown on the Earth It has been conjectured that stars may one day be formed by condensation of these gases, but no change has been detected in the Nebula in the short time (40 years) that it has been accurately studied A photograph shows much more of this and all Nebulæ than the eye is able to see even with the help of the largest instruments

MISS CAROLINE HERSCHEL
Caroline Herschel rendered invaluable assistance to her brother, Sir William Herschel She prepared charts for him, and after his death laboured to prepare his observations of nebulæ and clusters for publication Her work during her brother's life-time was largely clerical, and she would take down his observations as he made them at the telescope She found time, however, to do some observing, and herself discovered eight comets

in detail the generalities of the Copernican theory When in the course of this work we are introduced to the magnificent achievements of Tycho Brahe, Kepler, Galileo, Newton, Laplace, the Herschels and many great modern Astronomers, it will be evident how tremendous is the progress that has been attained and how impelling and fascinating the grandeur of the discoveries Absolutely beyond the wildest dreams of the ancients is this edifice of knowledge of the heavens which the intelligence of man has built up The instruments which he has slowly evolved multiply a thousandfold the vision of the naked eye

In this great march towards victory over the cosmos, women have taken a prominent place The Duchess Louise of Gotha, Caroline Herschel, Lady Huggins and others stand out pre-eminently And in modern times particularly American women are foremost in the interest they exhibit in the study of the sky

The study of stellar evolution brings a pleasure and enthusiasm difficult to rival or surpass Everyone has a chance to make discoveries even at this day The naked eye is capable of gauging numberless points of interest and instruction in the vast panorama of heavenly objects As to instruments, a binocular or a small inexpensive hand telescope is all that is necessary Persistent watching can still discover many things and the amateur is justified in nursing the not unreasonable ambition of doing some service for astronomical science and acquiring a little well-earned fame For change is the very essence of celestial phenomena, and imagination rightly exercised is the best guide to the aspiring astronomer

Have you ever pondered the mysteries of the Solar System? Aristotle tells us that the physicists of old believed that the Sun was conveyed by night across the northern regions to be in time to rise in the east next morning, and darkness was due to lofty mountains screening off the sunbeams during the voyage Eclipses

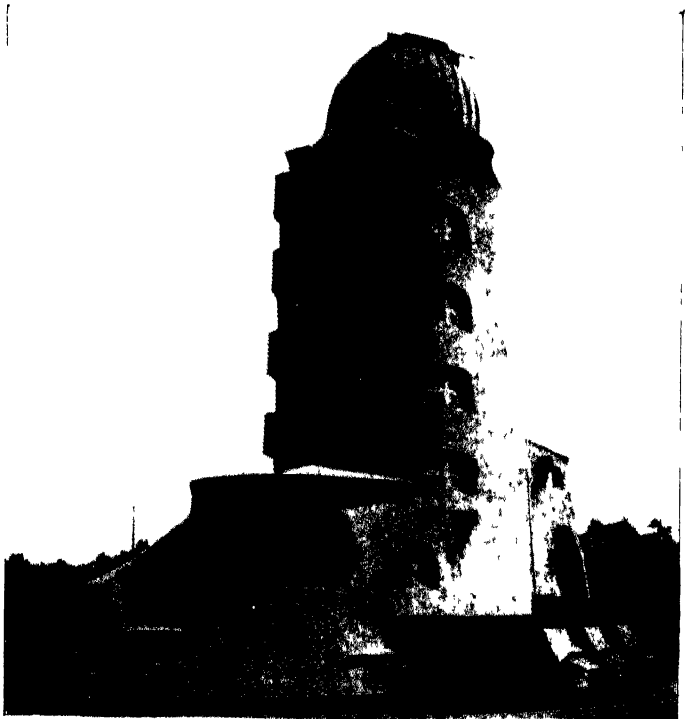
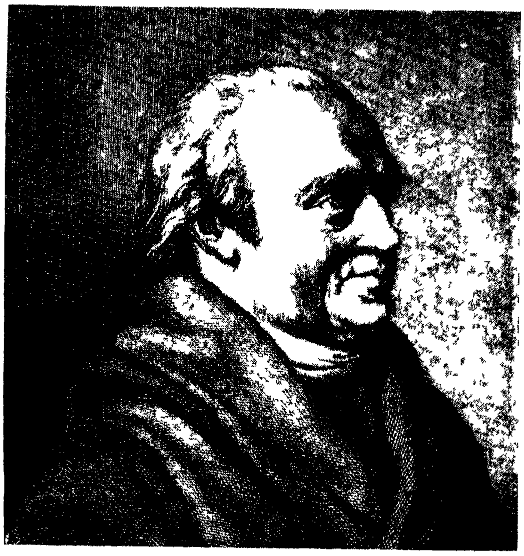


Photo by] [L N A

THE EINSTEIN TOWER
This unusual form of Observatory, first tried in America, contains a large telescope permanently fixed in a vertical position, hence the height of the Tower Such a telescope is very rigid and free from disturbing currents of air, which renders it specially suitable for the extremely refined observations necessary for the testing of the great theory, known as Einstein's "Theory of Relativity" The light of the stars is directed down the telescope by great mirrors moved by clockwork



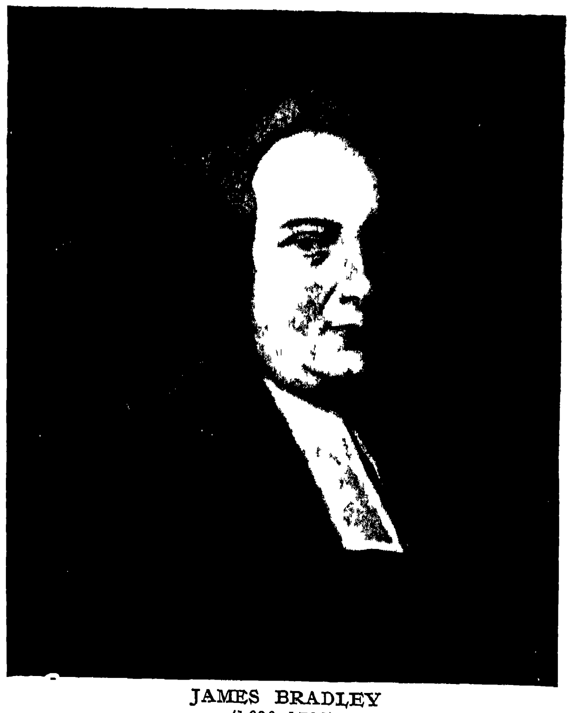
SIR WILLIAM HERSCHEL
(1738–1822)
Sir William Herschel was the greatest observer of the eighteenth century. In his early days as a poor music master he devoted his few spare hours to his hobby. Unable, through poverty, to buy a telescope, he set himself to make one, and he ultimately constructed his giant 40-foot telescope at Slough, near Windsor. He discovered the planet Uranus, and laid the foundations of modern sidereal astronomy.

of the Sun and other celestial phenomena, we read, struck terror into savages; and we know that the priests of primitive times made this ignorance and fear of uncivilised tribes a pretext for gain and undue advantage. Many of our most cherished superstitions are connected with the "Twelve Signs of the Zodiac", and yet how flimsy and unreasoned these superstitions appear once a little knowledge of the stars has been acquired. Indeed, it was once fancifully suggested that the stars were golden nails driven deep into the crystal of the heavenly dome. It was never realised that the rigid peace of the heavens was only apparent. And what of our Mother Earth which was for so long believed to be flat?

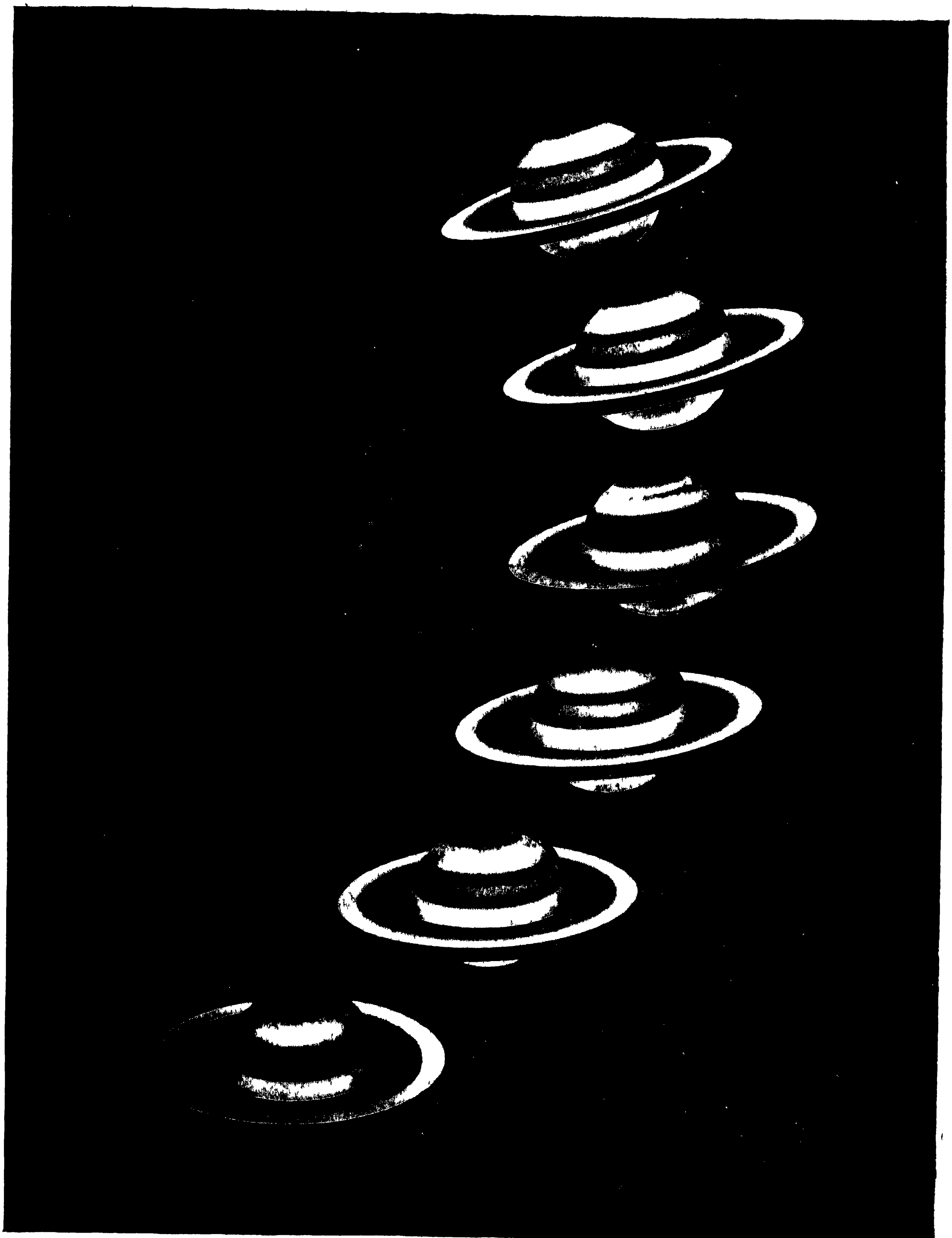
The Sun is the centre of the Solar System. By virtue of its immense gravitative power it holds the planets revolving round it in space. These bodies, including the Earth, move through space with velocities truly stupendous. But whence does the Sun derive this tremendous power of attraction? Is it in turn attracted and held in space by a still more powerful sun or suns, and does this arrangement proceed upwards *ad infinitum*? How do we know that in the stellar universe as a whole the Sun is but a speck? More than a million Earths could find a home in the Sun and yet at least 1,000 million such suns have actually been photographed by our modern telescopes and doubtless many more remain to be revealed.

This is an instance sufficiently powerful to impress us with the insignificant part allotted our Earth in cosmic evolution. Indeed, the Earth is comparable only to a snowflake driven by the roaring storm which mingles it in one grand chaos. At best it is a drop in the vast ocean of worlds. We live on a planet continually whirling and poised without visible support in space. Our nearest neighbour is the Moon, which is only 240,000 miles away. The distance of the Earth from the Sun is about 93,000,000 miles. That of the nearest of the stars is 25,000,000,000,000 miles! How are we enabled to measure these distances and how are we assured of their accuracy?

These and other questions will be answered in the course of this work. Everyone knows that the Sun is the source of all the heat and light which we on this Earth enjoy, and it is *the* fundamental condition of our continuous



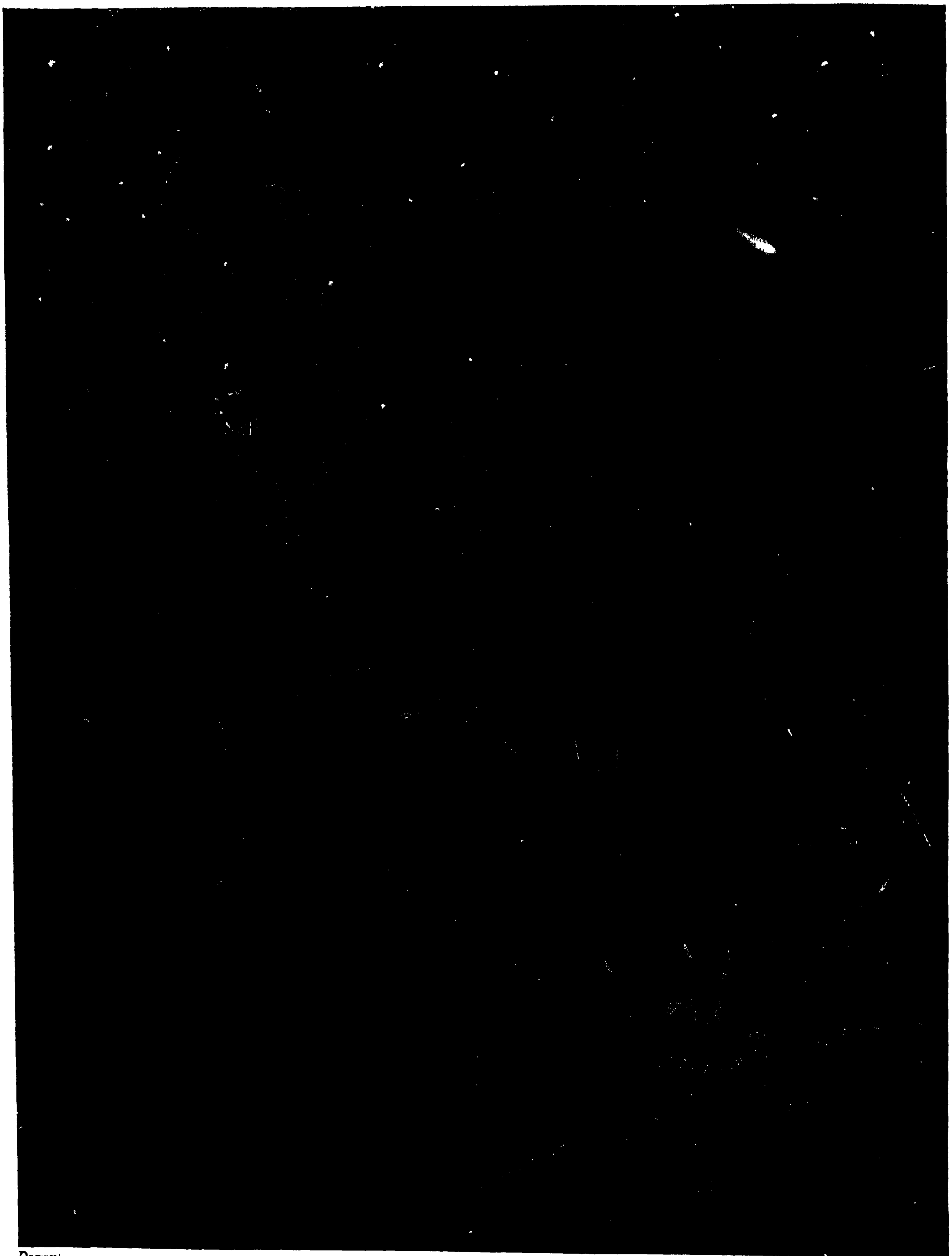
JAMES BRADLEY
(1693–1762)
Bradley succeeded Halley as Astronomer Royal. Some accidental observations made in a boat on the Thames gave him the clue to his explanation of a puzzling annual displacement of the stars, which he communicated to the Royal Society in 1729. This, with his discovery of a particular movement of the Earth's axis, was an indispensable preliminary to accuracy in fixing the places of the heavenly bodies.



Drawing] [L. R. A.

SATURN

The planet Saturn is distinguished by the possession of a unique set of appendages, which take the form of several concentric rings There is nothing else quite like them in the Heavens They are known to be composed of myriads of separate particles whose exact size is not known Two, at least, of the rings are partly transparent and stars have been seen through them as through a veil The black circular line in the picture represents a permanent fissure or gap between the two main rings Like Jupiter, the globe of Saturn occasionally betrays internal tumults by eruptions of spots



Drawn] [*By Allan Stewart*

HALLEY'S COMET IN 1066

In mediæval times superstition associated the appearance of great comets with terrestrial disasters and calamities A splendid comet appeared in the year of the Norman Conquest and the Saxon inhabitants of this land cannot have failed to connect the two events In those far off days the laws governing the movement of comets were quite unknown

existence on this planet Were the Sun suddenly to lose its radiative powers, animal and other life on this Earth would become extinct Whether some such fate is to be the ultimate end of the Solar System has been an open question for centuries and it still remains open Yet it is sufficiently established that the Sun is not a solid body like our planet, but a semi-gaseous globe radiating a fierce heat, albeit with less force than characterised its action millions of years ago It contains hydrogen, sodium, iron, magnesium, and other elements, all in the form of gas It has been calculated that it would take tens of thousands of years for the Sun to shrink even a particle of its present extent and still the heat which the Earth derives from the Sun would be in no wise sensibly diminished So far as human intelligence can see, the Solar System will have a continuous existence for millions of years to come

Again, le[illegible]sider the question from the sta[illegible]f the Moon Planetary globe[illegible]d through the gradual wastage [illegible] The Moon would seem to repr[illegible] condition which all will reach [illegible]tant future What, then, of th[illegible]members of the stellar univers[illegible]o what purpose, indeed, its ex[illegible] balance and self-regulating f[illegible]his divine mechanism with its [illegible]atory springs? But the conclu[illegible]f science in this connection are [illegible]ly hazy We cannot satisfactorily [illegible]ise a given state and at the same time [illegible]certain that it is really going to happen [illegible]e persist in the faith of our fathers and place implicit trust in the everlastingness of created things that if death intervenes [illegible]fe is always being created "The old [illegible]der changeth, yielding place to the new" [illegible]xpresses for us a deep-rooted and ineradic-[illegible]ble conviction which man cannot wil-[illegible]ngly let die

[illegible] It is, however, generally agreed that [illegible]the world was once a fluid haze of light" [illegible]ow it came about that the constituent [illegible]dies of our Solar System were set

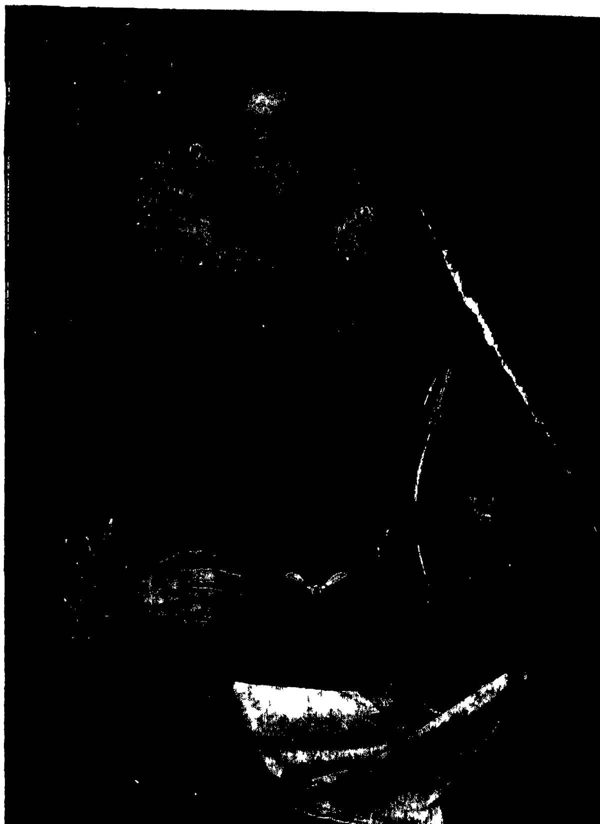
HALLEY'S COMET IN 1910

This time the same comet had a very different reception Halley, at the end of the Seventeenth Century, had shown that this body was periodic in its visits to our vicinity, returning every 75 years or so Since his time it has been seen at every visit At its last return in 1910 it was not well seen in England, but our photograph, taken at Johannesburg, shows that it was a magnificent object to Southern observers.

TYCHO BRAHÉ
(1564–1601)
The work of Tycho may be said to mark the commencement of the era of exact astronomy He was by far the most accurate of the pre-telescopic observers Frederick II of Denmark made him a grant of an islet in the Sound, where he built a mansion and erected magnificent instruments, which he used with consummate skill It was on Tycho's exact observations that Kepler based his famous laws of planetary motion

wheeling in the void is a question which we find more difficult to answer than our predecessors with their limited knowledge supposed How was the Earth-Moon system formed? It may be that in ages beyond human visualisation the Earth and the Moon constituted one fluid or plastic mass, but through rapid rotation a portion became detached and was whirled into space to form the Moon

The history of the planetary system is truly an absorbing study Greek mythology and poetry abound in allegorical references to the planets Mercury, Venus, Mars, Jupiter and Saturn have been known from time immemorial The orbit of Saturn marked the boundary of the Solar System as known to the ancients, Uranus and Neptune being discovered comparatively late in the history of Astronomy Neptune is in our own day supposed to be the most distant planet, but the existence of at least three trans-Neptunian planets has been conjectured by some astronomers At all events, it seems to be the case that the boundaries of our System are yet only provisionally fixed The time and manner of its formation are alike uncertain If the Sun is now a shrunken body compared to the vast dimensions of its structure long ago, we may believe there was a time when no planets existed and all were swallowed up in a sphere which extended beyond the limits of our System as at present known According to the famous theory of Laplace, the latter began as a "nebula," a mass of gaseous materials which was somehow set in whirling motion Progressive condensation of this distended body would exercise a quickening influence upon its rotational movement until fragments of its substance in the form of rings were successively whirled from off the parent body to condense later into the planets



KEPLER
(1571–1630)
Kepler is the real founder of modern astronomical theory He was a pupil of Tycho Brahé and came into possession of the latter's whole collection of observations of the planet Mars, and from additional investigations he disclosed, by geometrical proof, the harmonious plan upon which our System is ordered His Three Laws as to the paths of the planets constitute his most notable achievement The full import of these laws was first perceived by Newton, who showed that they were a necessary consequence of the Law of Gravitation

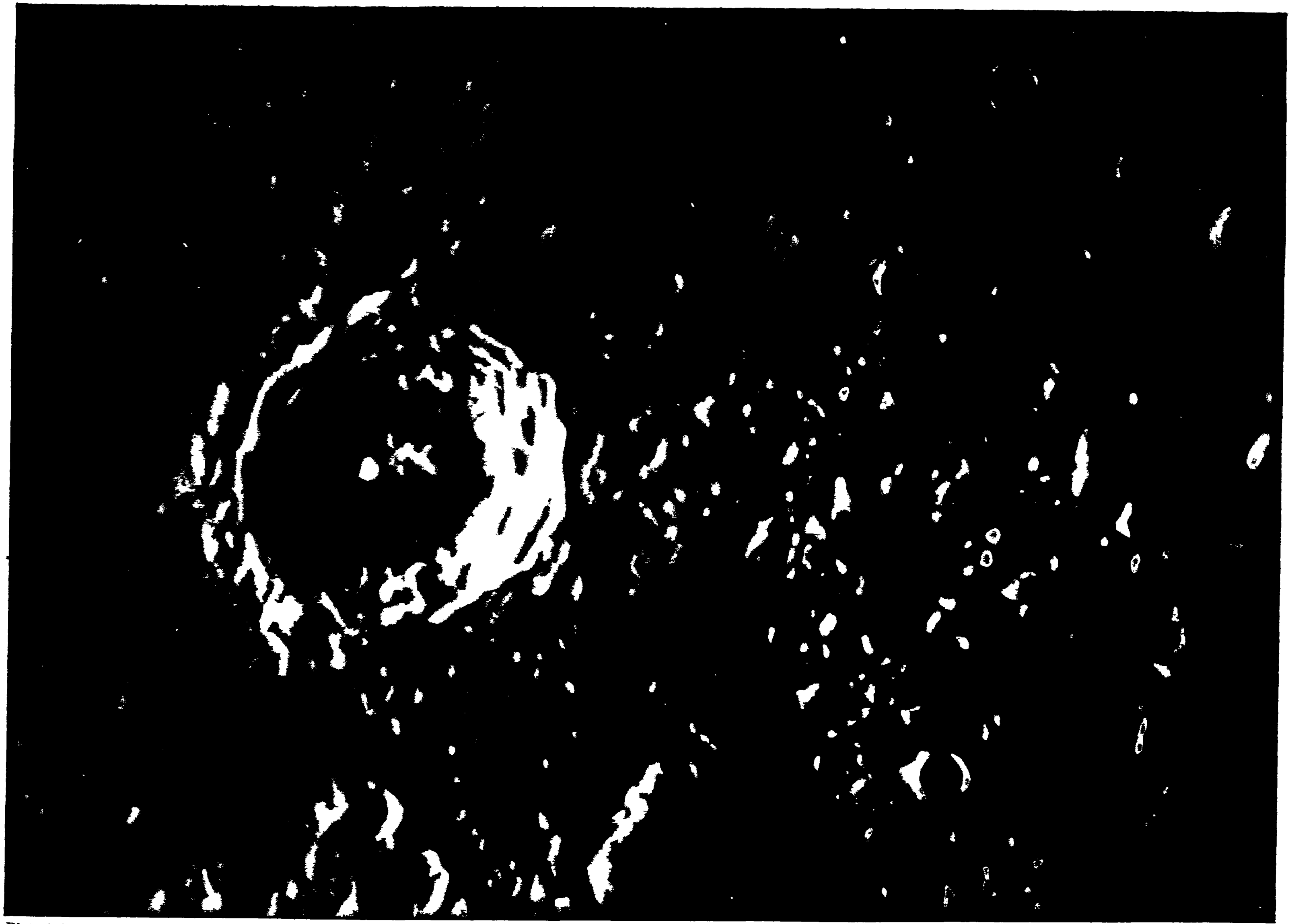
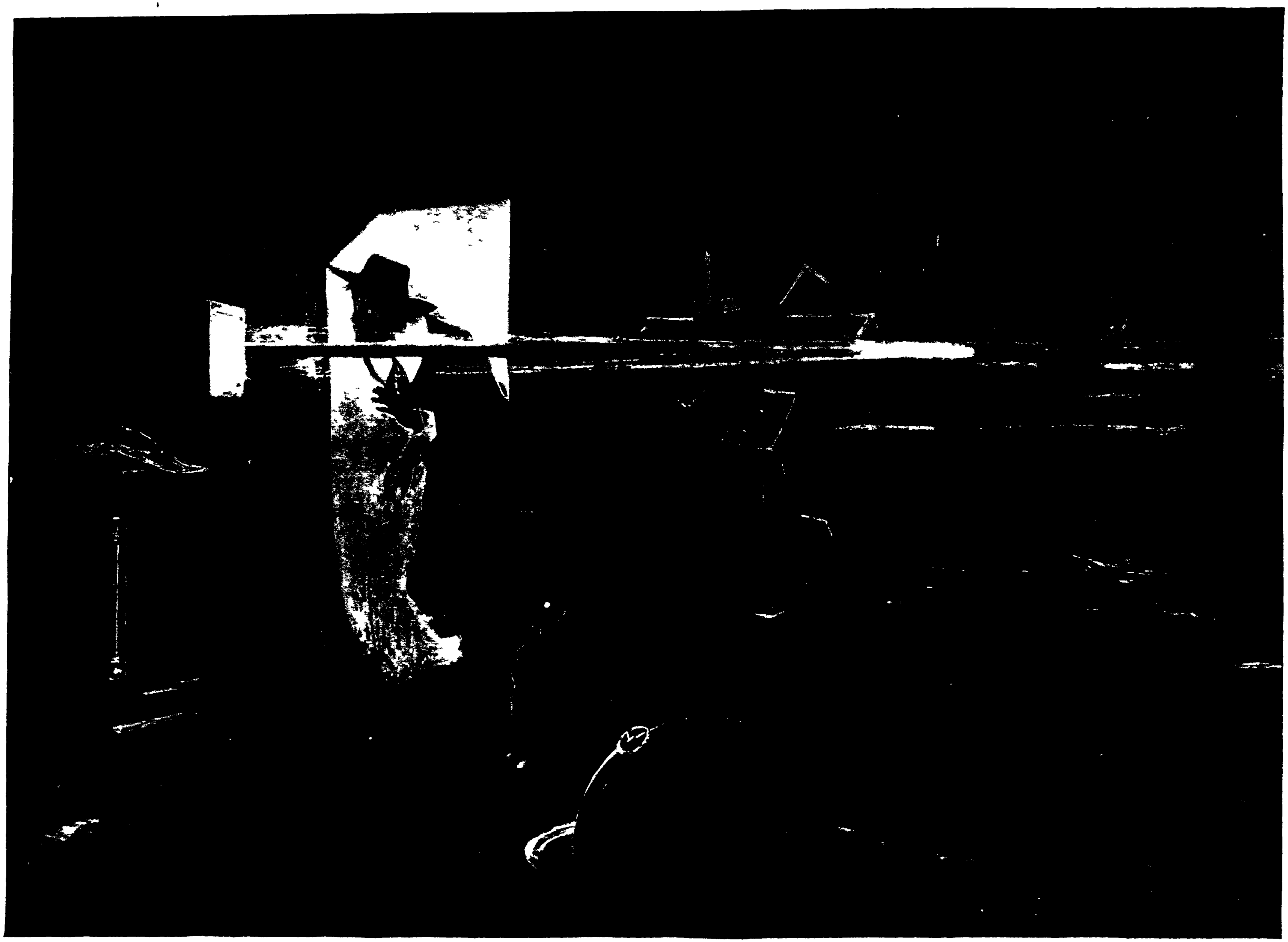


Photo by] [*The Yerkes Observatory*

A GREAT LUNAR MOUNTAIN, "COPERNICUS"

A lunar crater usually consists of a sort of basin with a conical elevation rising from the centre and a raised rim encompassing it. The bottoms of lunar craters are nearly always depressed—sometimes thousands of feet—below the general level. Thus, the central peak of the great crater Copernicus towers to 11,300 feet above the depressed plain from which it rises, but surmounts by only 2,600 feet the average level of the Moon. One characteristic of this crater is a series of bright streaks or rays (only seen near Full Moon) which radiate from it in all directions without visible origin. The crater itself is held by some to be volcanic, and by others to be the result of the impact of a great meteorite. There are many thousands of these craters on the Moon, their sizes ranging from a few hundred feet to 150 miles.



From the painting] [*By Eyre Crowe, A R A*

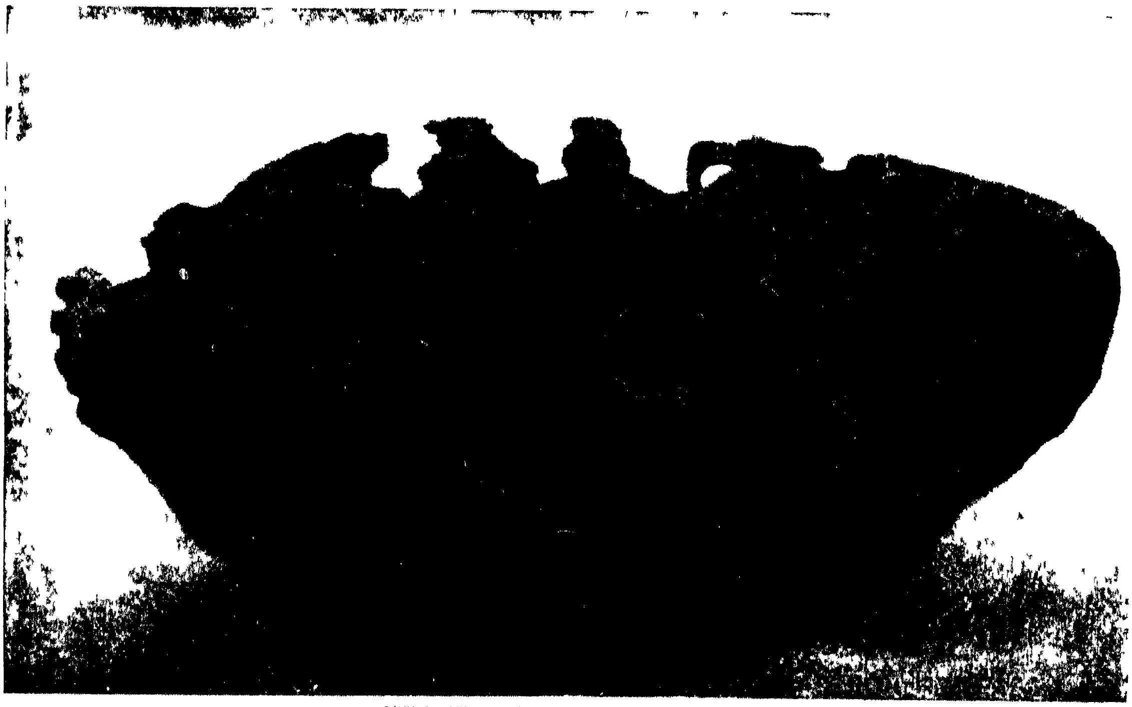
JEREMIAH HORROCKS (1619—1641)

Horrocks has been termed the Founder of English Astronomy He was the first man to observe a transit of Venus (in 1639) As he predicted, Venus passed across the lower part of the Sun's disc, and the mistaken prediction of Kepler was disproved During the last year of his life—his twenty-first year—Horrocks worked on the motions of Jupiter and Saturn, and projected investigations on Comets and Tides In the short time at his disposal, and with very inadequate means, he made wonderful progress Dr Wallis, who edited his papers exclaimed "Had he lived what would he not have done!"

It was further suggested that repetitions of this process in the case of the embryo planets resulted in the birth of their satellites

More recently difficulties have been raised which render this famous theory untenable so far, at any rate, as *our* System is concerned, and some other attempts to find the key to the process followed in the evolution of Sun and Planets will be described in the course of this work

The present physical condition of the bodies constituting the Solar System has always been a source of absorbing interest, though still in part conjectural The power of the modern telescope has proved conclusively that there are tremendous disturbances within the Sun's compass All that we know of their action is what we can discover about the prominences and Sun-spots which take shape and speedily change in form The much nearer position of the Moon to the Earth has enabled us to distinguish many features bearing a certain similarity to objects on the surface of our own planet In particular Mars has been carefully mapped out into areas, hypothetically regarded as land and water, to which very bizarre names have been given But great controversy rages over the configuration of this planet



THE WILLIAMETTE METEORITE

Falls of large Meteorites are sometimes accompanied by terrific explosions and sharp reports that can be heard for many miles around, often causing the ground to shake as in an earthquake The origin of Meteorites is not definitely known, but it has been observed that they travel along the same paths as certain comets, of which they may have once formed a part The Williamette Iron Meteorite, weighing 16½ tons, was found lying in a forest at Williamette, Oregon, U S A, but was not deeply buried

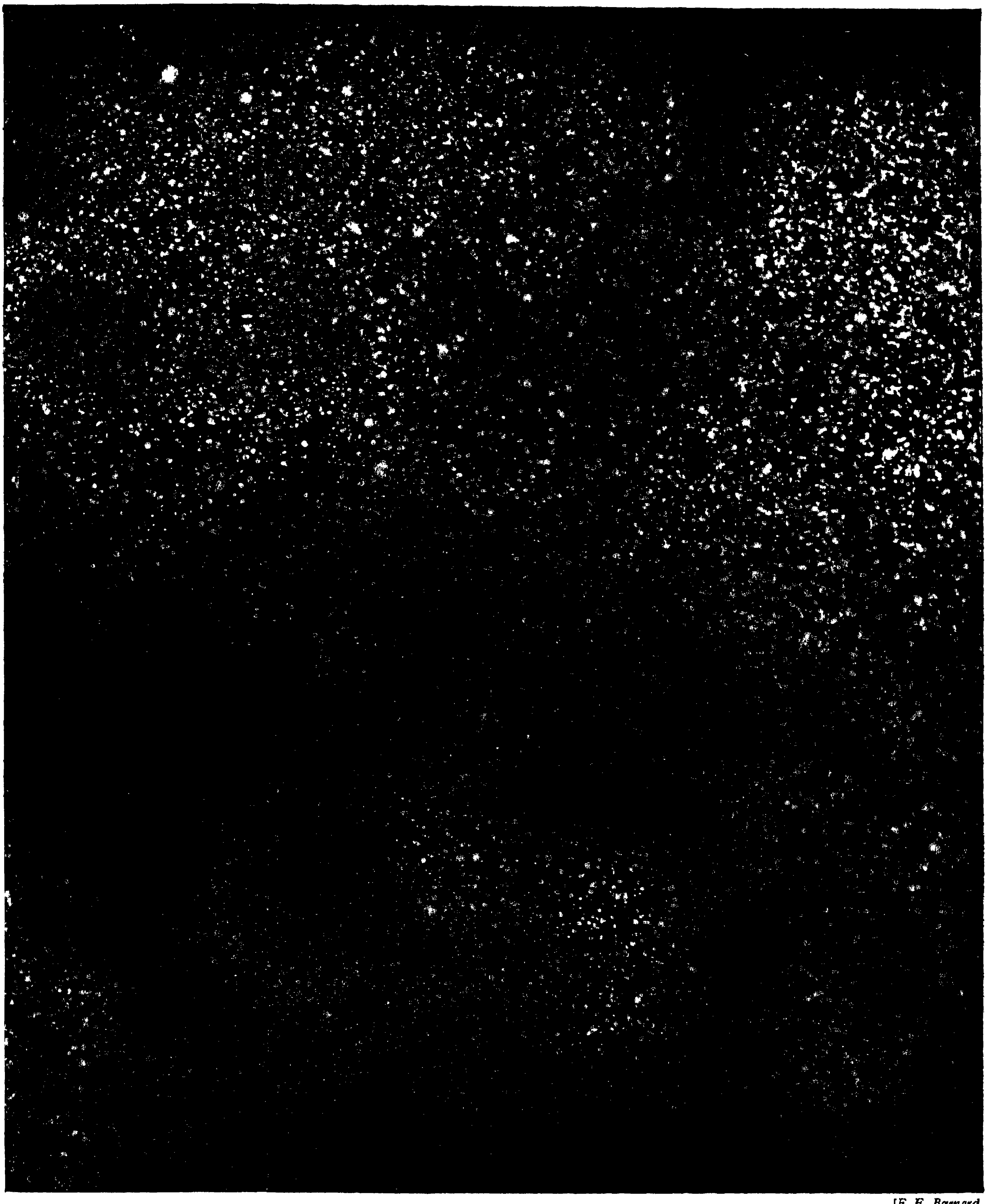
These considerations give rise to the question are the heavenly bodies peopled? Though this is a problem which we cannot definitely solve, it is at all events quite possible that one or more of the planets contain living beings in some respects comparable to ourselves It is hardly beyond the limits of reasonable conjecture that the peoples of other planets may be pursuing investigations of a like character to our own astronomical studies The Earth may be a source of perennial interest to the inhabitants of another world, and for all that we know they may be in a far more progressive stage of civilisation than we are, and their discoveries of the wonders of the universe such as we shall not attain in the next thousand years

Comets, like eclipses of the Sun, instilled feelings of profound dismay into the peoples of old, who thought they were the manifestations of the Divine wrath for sins which required immediate expiation Many of these comets have "tails", and they present a brilliant spectacle in the grand silhouette of

Photo by]

THE MILKY

A faint band of hazy light which the ancient Mexicans aptly termed " the sister of the rainbow," spans the celestial dome and extends acro
Various explanations were given of it in ancient times, but to-day we know its radiance to be due to the presence of millions of stars, dimme
opinion that it marks the limit of the visible universe, and that a



WAY

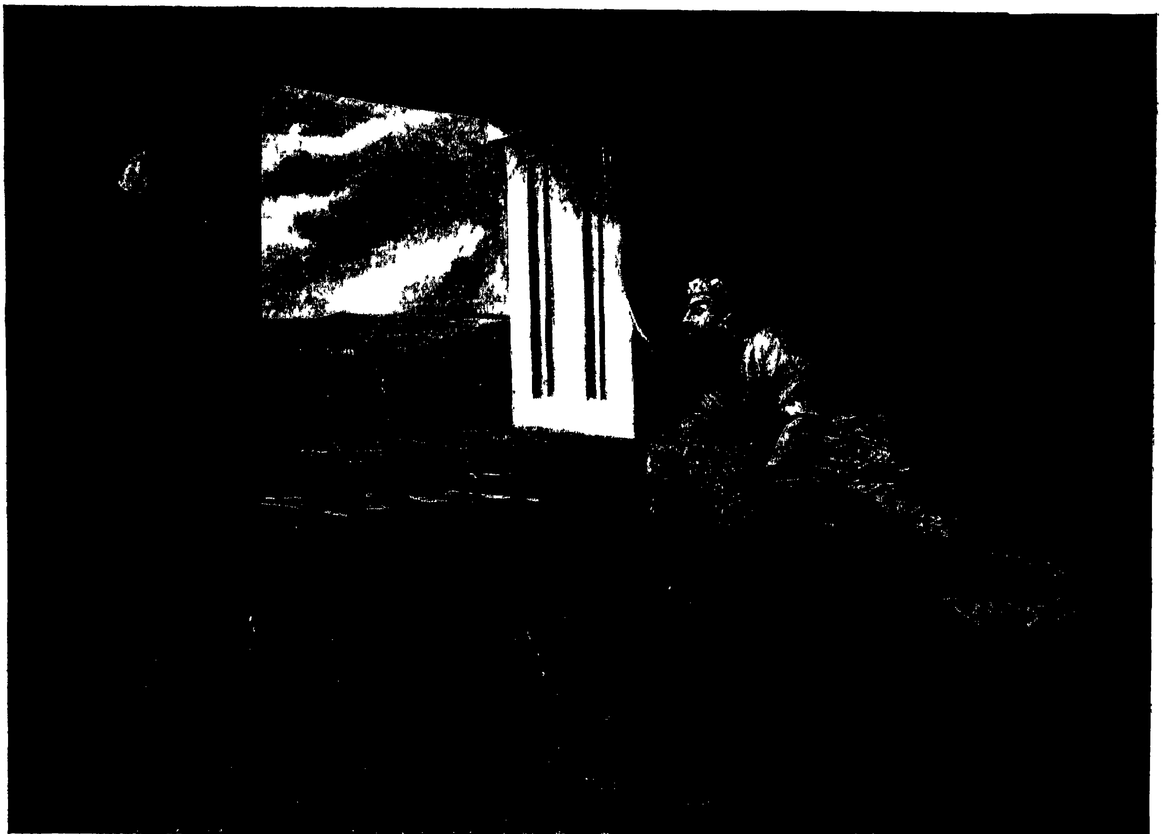
[E E Barnard

both Northern and Southern Hemispheres This great luminous belt, seen at its best on a clear August or September evening, is the Milky Way. and huddled together by their vast distance The Milky Way encompasses the whole of our stellar system, and some astronomers are of immense space, empty to our senses, lies on the farther side of it

the heavens Photographs of cometary displays have afforded abundant means of studying their composition What do we know of the luminous trails of shooting stars, the result of brief and sudden contact with the air above us? What explanation can we adduce for the showers of "meteors" which fall periodically upon the Earth from the sky, apparently from nowhere?

Now let us peep for a brief moment at the sidereal system Strong though the attraction is to dwell thus widely upon the untold wonders of the sky, the interest of the reader will be aroused to a still greater extent than the space of this Introduction allows, in the successive parts of this great work He will be introduced to each celestial phenomenon in turn, and he will come away from a perusal of the complete story with thrilling emotions and with his mind opened wide to new sensations and intellectual pleasures never before thought possible for his enjoyment

We have already referred to the picturesque explanation given by the ancients of the starry

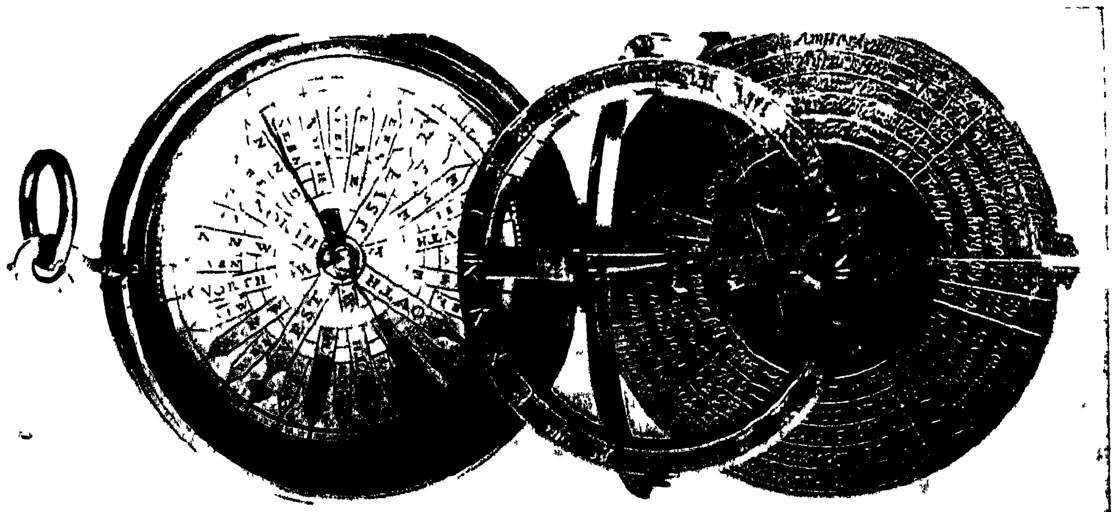


Painted by] [*M Doiaston, R B A, N B A*

THE ECLIPSE OF THE SUN, 15th JUNE, 763 B C

For some years Assyria had been passing through a period of weakness Matters reached a climax in 763 B C, when the total eclipse of the Sun was taken as a terrible portent of the wrath of the gods Ashur-dan III is watching the eclipse He met his death later in the year, and the country was given over to civil war and plague

firmament It is the great distance of the stars from the Earth which makes them appear stationary points, glittering in the dusk Undoubtedly, they are the same as those which Columbus saw when he peered anxiously for the desired land at dead of night But the reader will be astonished to hear that there are stars in the heavens which move through space at thousands of miles a minute, and yet we cannot detect their motion except by the comparison of observations made at considerable intervals of time—usually many years To all intents and purposes we perceive them to be fixed The number of stars that are visible to the naked eye is very limited, though they appear to be



In the Naval Museum, Greenwich Hospital

SIR FRANCIS DRAKE'S ASTROLABE

This is now an obsolete astronomical instrument It was used for taking the altitude of the Sun or Stars, and for other observations One of its most important uses was in navigation

innumerable It does not exceed the number of inhabitants in a small town, but as seen through a telescope, or better still on photographs of the milky way, the richness of the heavens is astonishing! In reality the stars are majestic suns, and the average distance between any two neighbouring stars is several thousand times the extent of the Solar System How unimaginably vast is the universe! The tremendous gap which separates us from the stars blinds us to their real significance in the heavens. Turn centuries into seconds, stellar distances into arm's lengths, celestial bodies into particles of dust,

THE NEBULA IN COMA

The Nebula in Coma consists of diffuse matter and is probably in an early stage of development, containing no stars as yet It lies on the borders of the constellations known as Virgo and Coma Berenices The dark stripe is due to cooler and less luminous matter lying on the outskirts of the Nebula and hiding from us some of the bright matter near the centre The Nebula is really shaped somewhat like a lens with its edge turned nearly towards us

and the Universe would show the stars rushing wildly to and fro in ceaseless turmoil, some vanishing into utter darkness, and others suddenly arising from nothingness! The stars are in every stage of growth, coming and going like ourselves

Among the more strikingly beautiful objects in the stellar universe must be ranked star clusters and nebulæ It is impossible to contemplate several thousand suns massed together in an apparently small region in space—and sometimes in globular form—without wonder as to the origin and destiny of such systems The more faintly luminous nebulæ are best studied photographically, but the famous cloud of glowing gas in the sword of Orion is to ordinary telescopic vision perhaps the most mysterious object at which the intelligent observer can look Quite different, apparently, in physical constitution and distribution as well as in form from objects of this type, are the spiral nebulæ, but

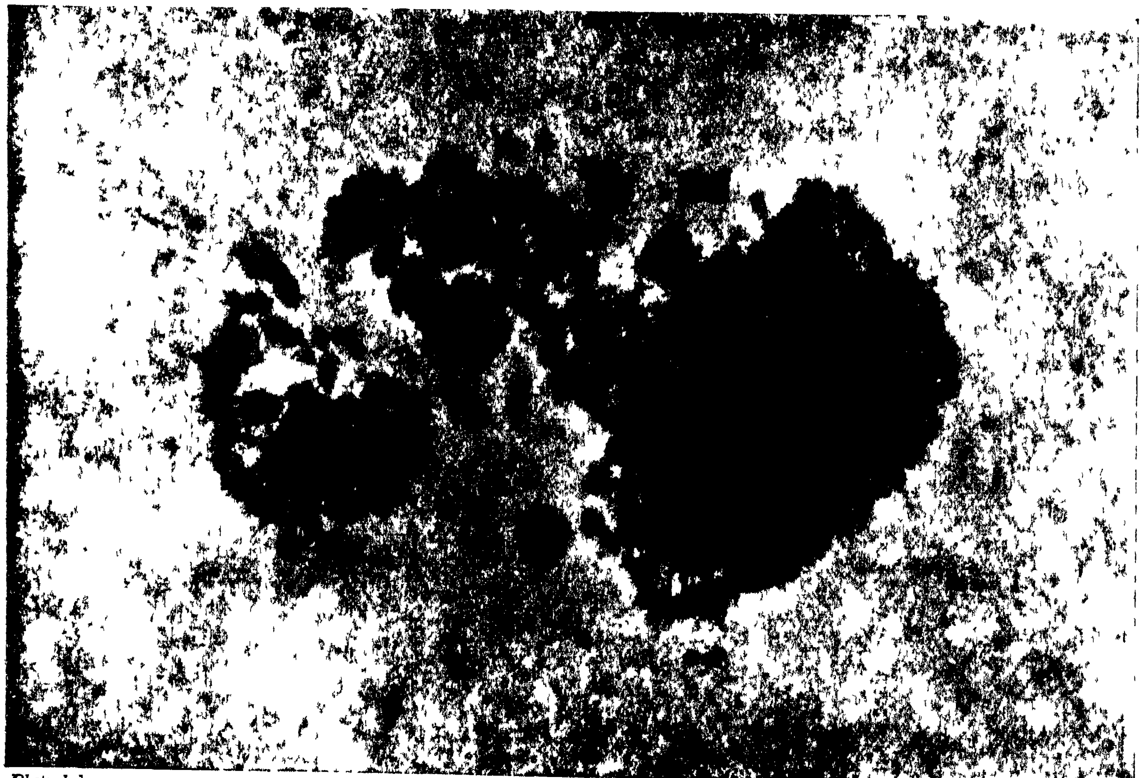


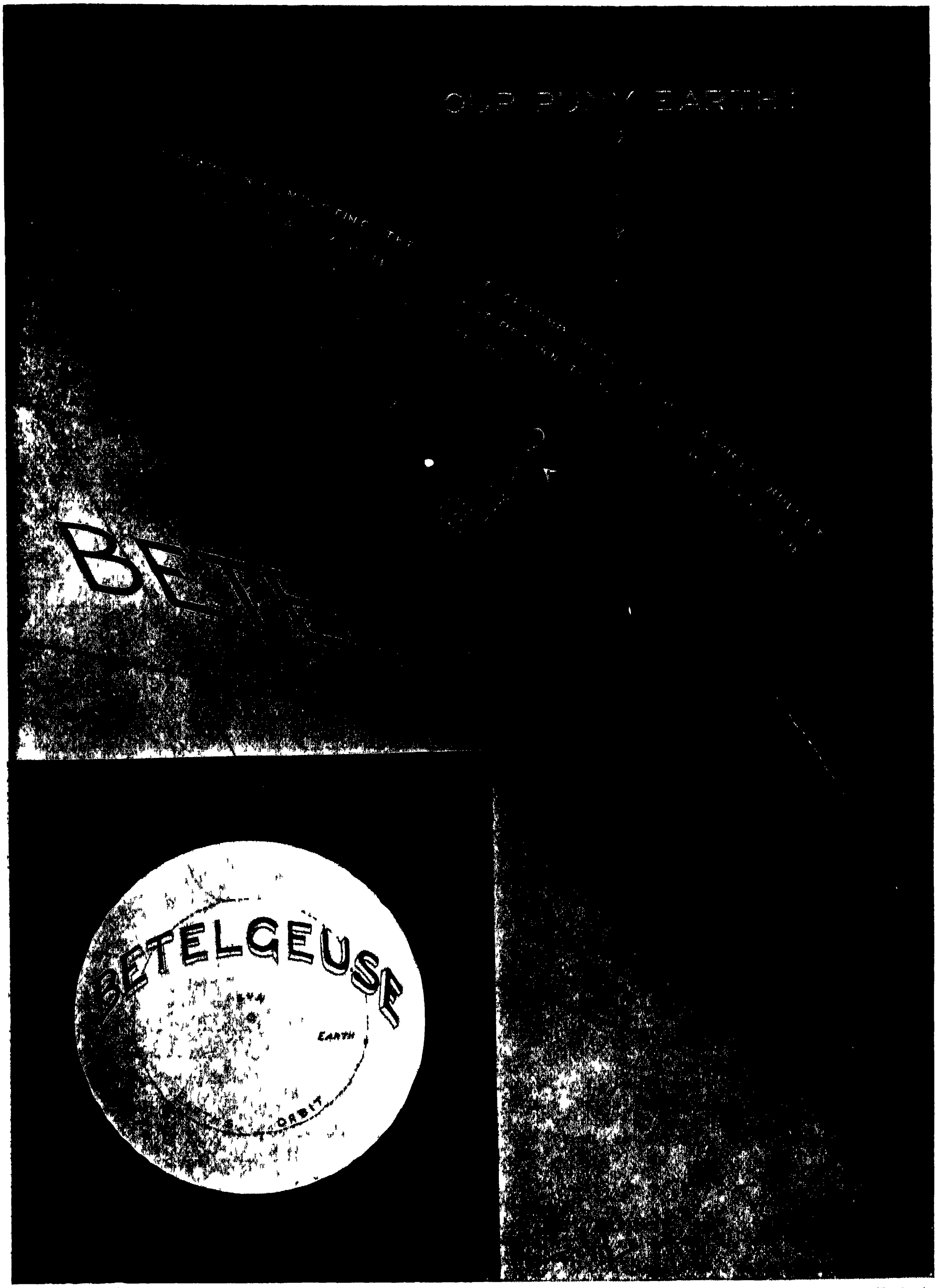
Photo by] [*Greenwich Observatory*

SPOTS ON THE SUN

These were observed by the Chinese thousands of years ago, but, before the invention of the telescope, little or nothing was known of them It is now established that they are temporary apertures in the bright surface of the Sun through which the comparatively dark interior becomes visible. Many of them are large enough to contain the whole Earth many times over, and last for several weeks, during which they are constantly changing in size and shape Sun-spots are usually plentiful at intervals of eleven years and are known to be closely associated with solar electrical or magnetic storms There are two main features in a Sun spot—a dark nucleus known as the Umbra, and a lighter border, the Penumbra

here again we depend for most of our knowledge of them on telescope and sensitive plate working in concert And in any endeavour to unravel the secrets of the past and account for the birth of suns and systems, the nebulæ of both kinds have probably much information of value to impart They are, perhaps, the most significant objects in the universe

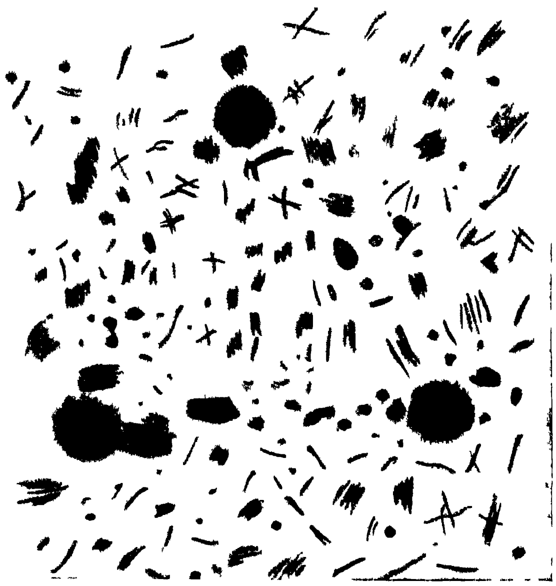
Not everyone is aware that our eyes derive their power of sight from an external source, that it is due to the properties of light, whether inherent in or reflected by the objects we observe. Light gleaming out a thousand miles away is almost immediately visible to the eye, for it travels at the rate of some 186,000 miles per second It takes only $1\frac{1}{4}$ seconds to reach us from the Moon and $8\frac{1}{3}$ minutes to come to Earth from the Sun The telescope, camera and



By permission of] [L J 4

BETELGEUSE ONE OF THE LARGEST KNOWN STARS

Betelgeuse is the leading Star in the Constellation of Orion Its name is derived from an Arabic word meaning *shoulder*, because it is situated on the right shoulder of the giant Orion on the old celestial globes It is reddish in colour and slightly variable in light It is one of the ruddiest of the brighter stars and is a far less compact body than our Sun In the above fanciful picture the artist has purposely ignored the effect of Gravitation, which would make impossible the experiment here illustrated



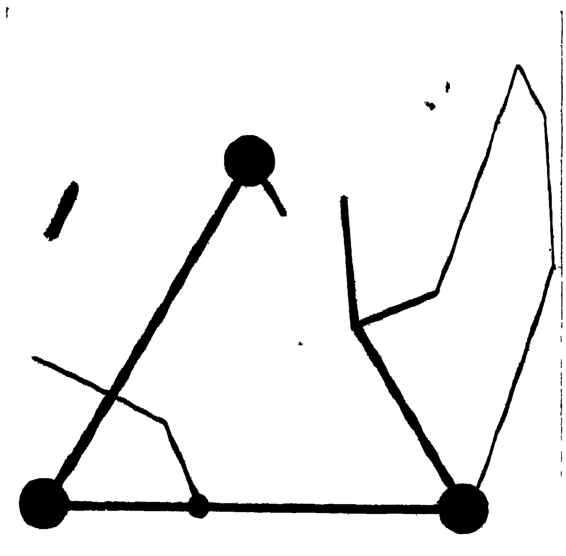
CANALS IN MARS?

These two drawings support the contention that it may be only distance which causes the markings on Mars to appear as straight lines Here are shown a number of irregular patches—

spectroscope help in translating the speech of light the prism is its special interpreter! By its power of "dispersing" the rays of white light into its components, we obtain not only the beautiful and varied colours of the spectrum, but information which reveals some of the profoundest secrets of the heavens

It is instructive at this point as well as of interest to note the change in outlook and scope which has marked the progress of Astronomy, say, during the last hundred years

Perhaps we may not unfairly describe the Astronomy of a century ago—and indeed until after the middle of the last century—as essentially formal or mechanical in character What was especially aimed at was the greatest possible accuracy in determining positions and the perfecting of our knowledge of the mechanism of the heavens At that time it was scarcely thought possible that man might some day progress from a knowledge of these things to a determination of the chemical constitution, the life history, and the internal economy of the distant stars, yet such studies constitute a very large part of astronomical research to-day The fact is, the success of Kirchhoff, Bunsen, and other great physicists of the middle of the Nineteenth Century, in showing how the absence of certain rays from the light of the Sun and stars might be explained, opened the way to a vast and hitherto undreamed of territory which astronomers, following up the pioneer work of Huggins, Lockyer, and other early spectroscopists, have continued to explore with the most conspicuous and amazing success



CANALS IN MARS?

—which contract into a continuous series of lines with circular points of junction when viewed at a distance of thirty feet

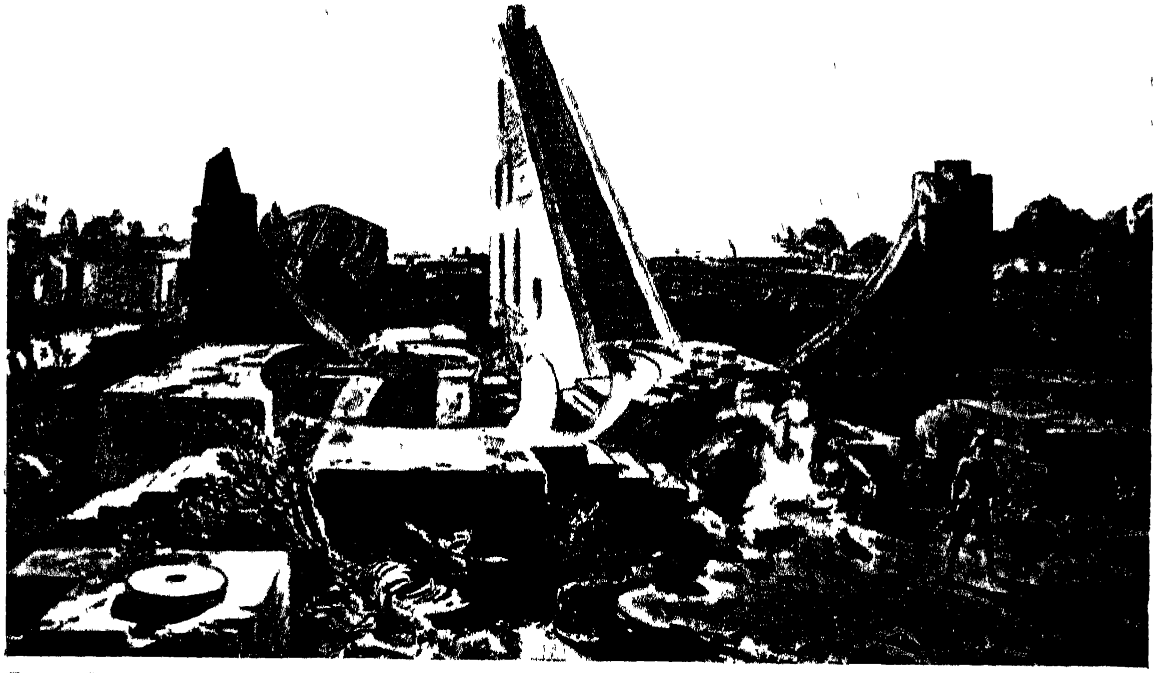
Prior to the year 1838 the distance of not one single star was known, and till even comparatively recent times our knowledge of stellar distances was limited to those of a small number of the Sun's nearer neighbours To-day, thanks to our ability to read with the spectroscope the messages contained in star light, the distances of thousands of stars, which could never have been measured by the old trigonometrical methods, are being determined with ease, and our knowledge of the sidereal system is consequently advancing at a rate which exceeds the wildest dreams of a century ago

And another point which has become abundantly clear to all students of Nature is the oneness of physical science Our fathers placed the sciences in a number of separate compartments We are learning now that this cannot be done No one can draw, *e g*, the boundary line between Physics and Astronomy there is none The two sciences overlap They are indeed but different phases of what is essentially one,

and for proof of this it is sufficient to recall the fact that the recent researches by Eddington and others into the constitution of the stars are based on what has been learned about ions and electrons and the structure of the atom and other related phenomena by observations carried out in our physical laboratories

And when we further remember that the very foundations of science—our ideas of force—our conceptions of what is meant by standards of length and duration and so forth—are being revised and modified, and a new light thrown upon the whole of the physical universe, we realise how wonderful are the times in which we live, and how extraordinary is the rapidity of our progress What, we may well ask, will be man's outlook on Nature one hundred years hence ?

It is altogether impossible in this introductory survey of the scope of astronomical science to convey in adequate terms the gorgeous nature of the subject with which we are dealing An



From the Indian Section] [*Victoria and Albert Museum*

JAI SINGH'S OBSERVATORY AT DELHI, 1719

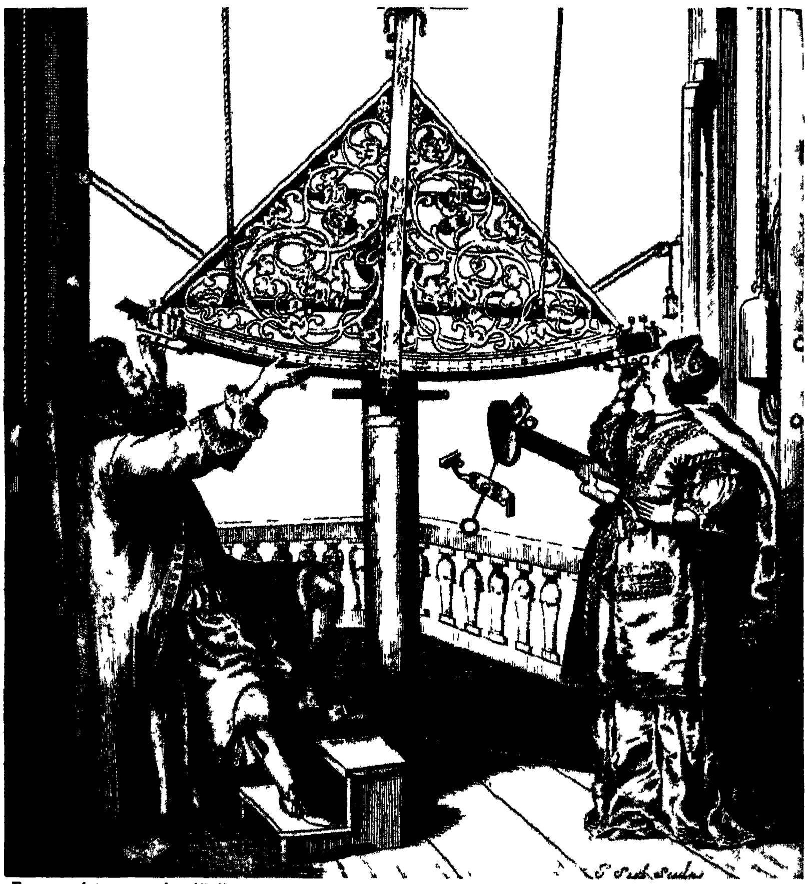
Raja Jai Singh Sawai (the Excellent) of Jaipur (1693–1743) was a famous man of science He built five observatories, *viz*, at Delhi, Benares, Mathura, Ujjain and Jaipur

introduction can but sketch the general characteristics of a subject just as the eye in a cursory glance over the heavens takes in but a very vague impression to begin with Nevertheless this Introduction itself may serve, perhaps, to make us marvel at our " colossal insignificance " and to revere the created works of a Supreme Intelligence Flowers and men, stars and mountains may pass away, but the stream of Time rolls on for ever

* * * * * * * * * * * *

The scale of the heavenly domain is such that it is difficult for human faculties to grasp its full significance But the gain derived from astronomical studies is in an intellectual and

moral sense incalculable It inspires with a profound and reverent regard the whole outlook of man. It fills him with a feeling of modesty and pathos at the small part he plays on the universal stage In the countless orbs which constitute the stellar universe, wherein his own Mother Earth is a planet of an inferior order, what power does he possess to influence the ceaseless tide of things, changing and ever changing ? Yet we must remember that the human mind has been endowed with a power of insight and analysis which in itself is a gift pregnant with untold potentialities That it has shown itself capable of mapping out the heavens in a manner that has almost strained its own life-force and made it question its own limitations in its quest for truth seems to imply that the ground of discovery is scarcely touched The appetite for knowledge has only been whetted, and every increase in its acquisition serves but to increase the area of conscious ignorance

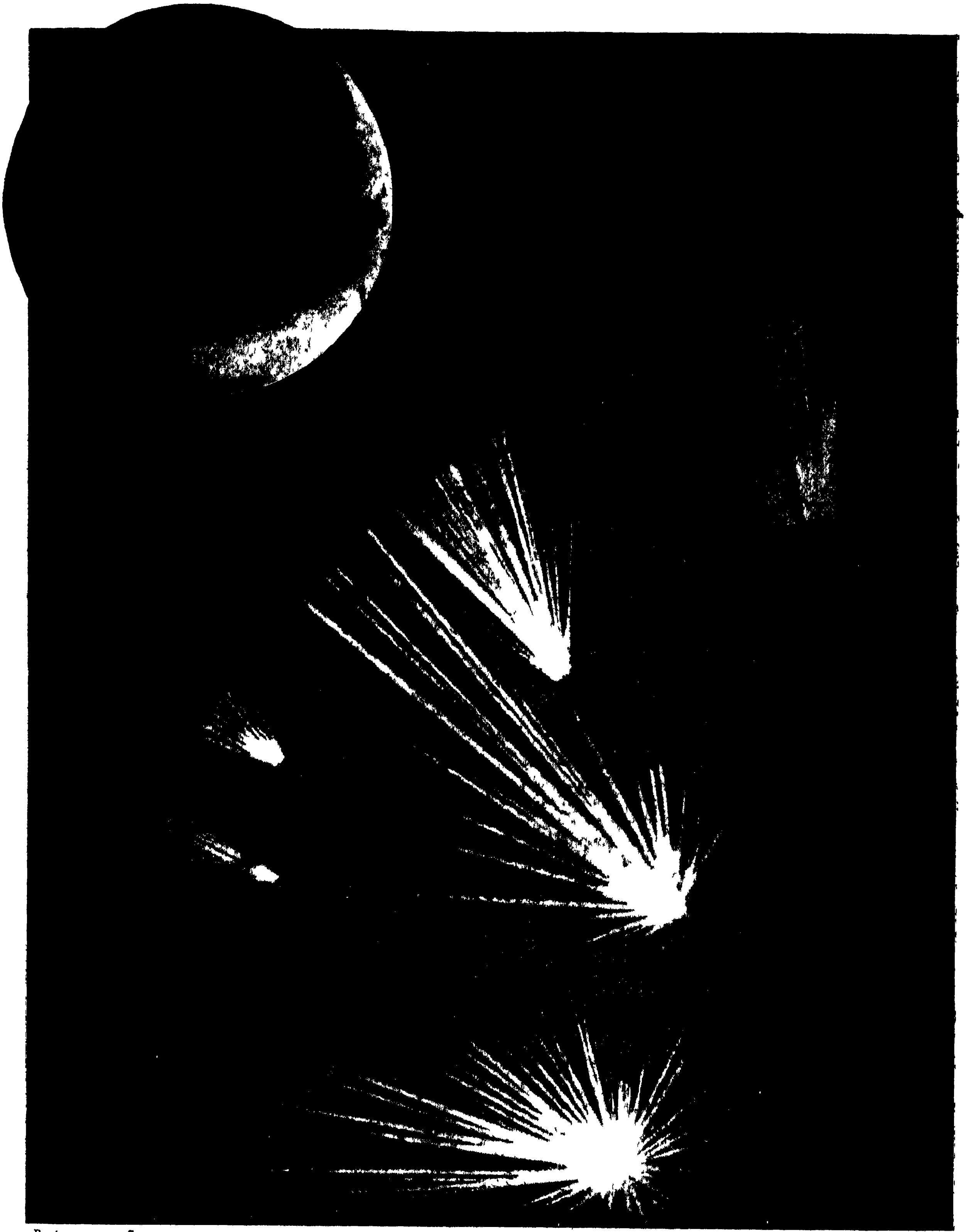


From "Astronomy for All"] [*By permission of Messrs Cassell & Co, Ltd*

HEVELIUS AND HIS WIFE MEASURING STELLAR ALTITUDES

Hevelius (1611–1687), celebrated for his careful drawings of the Moon and for the tenacity with which he clung to his old instruments, refusing to adopt improved telescopic methods, was one of the most accurate of observers without telescopic sights A City Councillor and Astronomer, he possessed a very fine Observatory, called the Sternenburg ("the Starry Fort"), at Danzig His wife has been called "the first woman astronomer" She was her husband's trusty comrade and rendered assistance by her accurate reading of his instruments

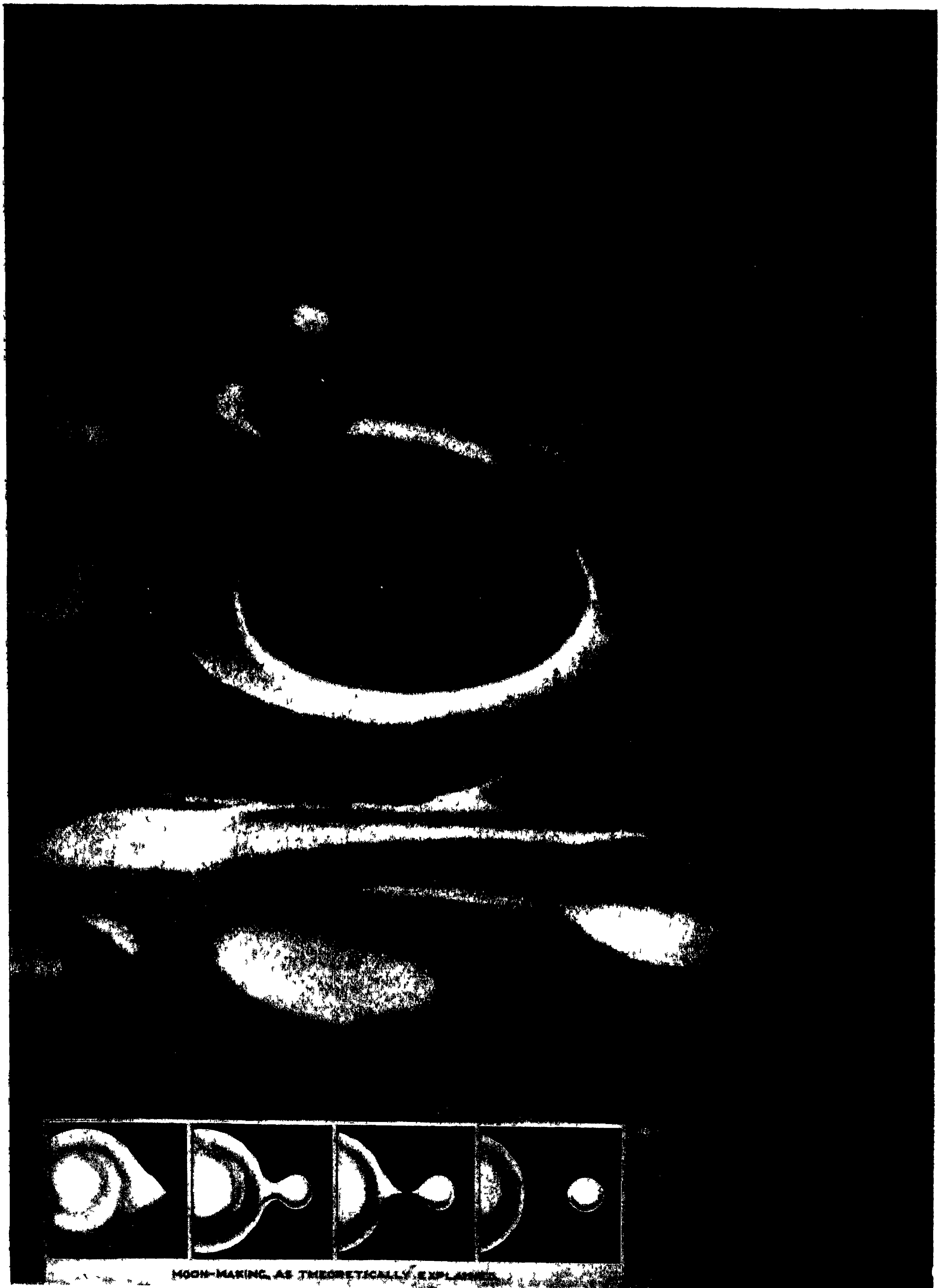
It may be asked, what benefit is conferred on mankind from astronomical studies ? Our knowledge of the size and shape of the Earth, the determination of a vessel's position at sea, our time system without which commercial life would be in hopeless confusion, are all derived from observations of the heavenly bodies But there are other than utilitarian considerations The supreme object of knowledge of whatever kind is not in the knowledge itself, but in what that knowledge implies Plato in constructing his ideal republic affirmed that "knowledge is virtue" To know is to be apprised of our position on this Earth and to mould our lives in accordance with the dictates of reason and truth It is only the ignorant who despise the teachings of garnered knowledge Of studies Bacon said that "simple men admire them, crafty men contemn them, and wise men use them" And in another place, "There is no pleasure comparable to the standing upon the vantage ground of truth" For, as our teachers have taught through the centuries, knowledge is the sole pass-key to right living and high thinking



By permission of] [*L. E. A.*

MAGNETIC STORMS ON THE SUN

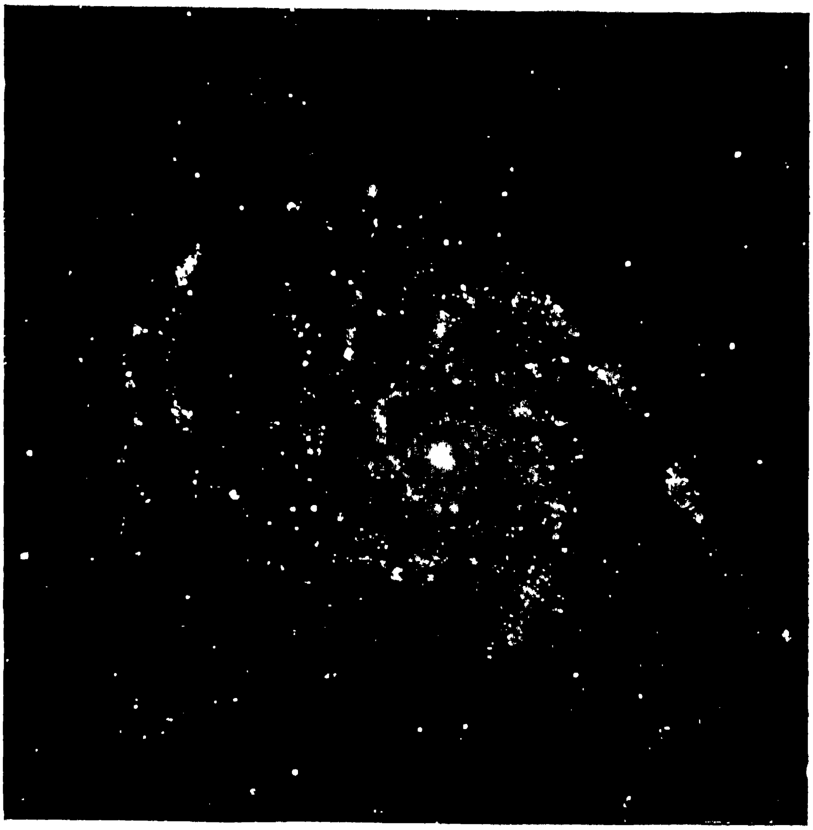
The Sun's surface is the seat of more or less constant magnetic and electrical disturbances, particularly in the neighbourhood of large spots. Invisible streams of electrified particles are projected into space in various directions, and it frequently happens that our Earth encounters one of them. The result is then a violent magnetic storm, sometimes severe enough to disorganise all telegraphic communication for some hours. Such storms are generally accompanied by brilliant displays of the Aurora.



By permission of] A PART OF THE PLANET JUPITER "THE GREAT RED SPOT" [*L T A*

This phenomenon first appeared clearly in 1875, growing steadily deeper in hue until it formed the most prominent object on the disc of the planet. The colour of the spot, coupled with the fact that powerful disturbances were observable in its immediate vicinity, led to the suggestion that it was due to the local generation of enormous heat, and that the surface had probably been rent asunder by a kind of volcanic eruption. The Red Spot was fully 20,000 miles in length at times, so that the disturbance—whatever its nature—must have involved an extensive area. It was plainly visible for a quarter of a century, but is now only barely distinguishable. All this seems to be conclusive as to the impossibility of organic life on Jupiter.

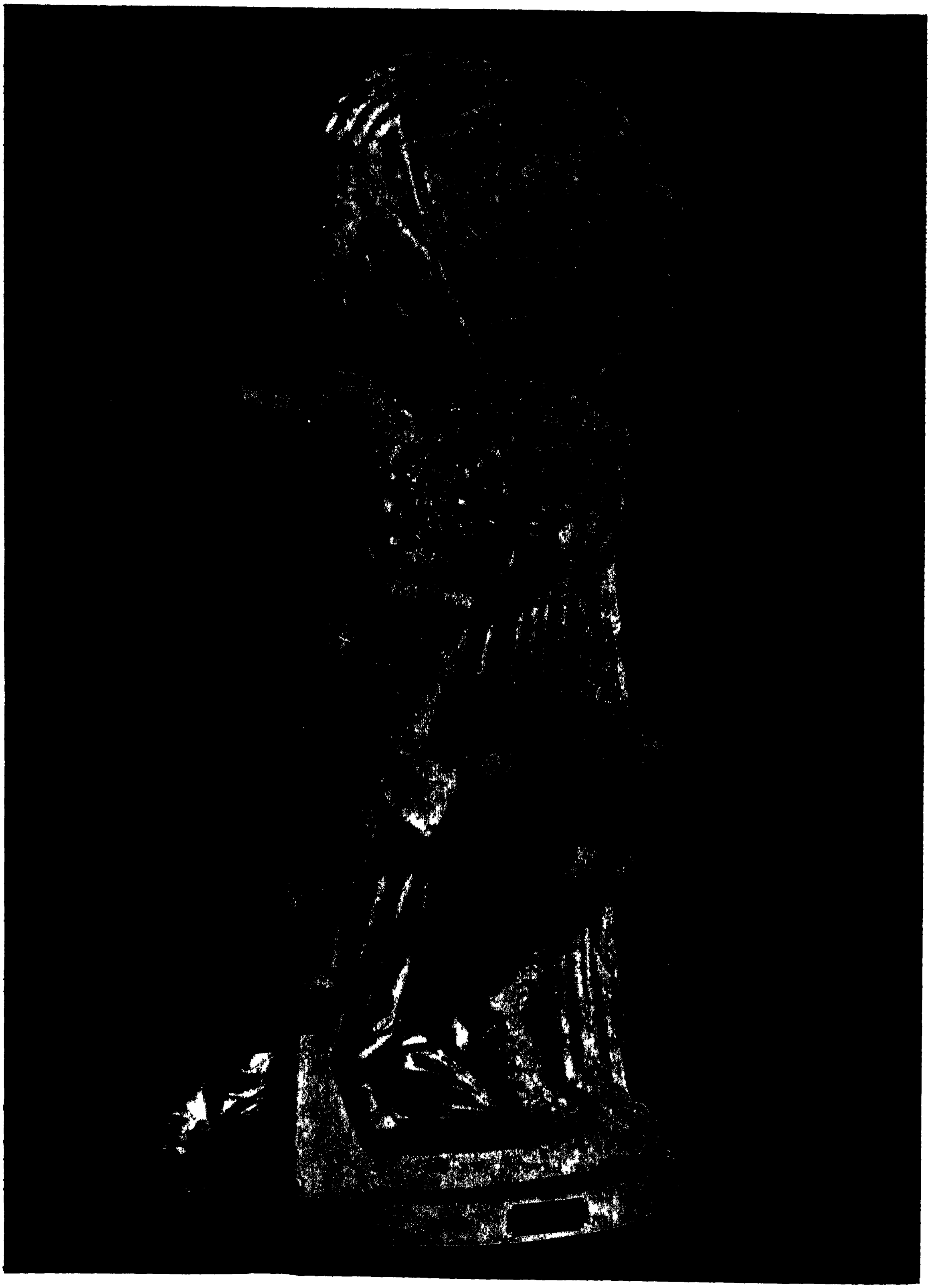
It is thus we should view astronomical studies A writer once had it that Astronomy was a "science of pure curiosity" But he did not sufficiently grasp the import of the knowledge thus gained Had he done so, he would have seen that the ever-expanding mass of astronomical research is the prelude to the understanding of our world through our diagnosis of the heavens Apart from the practical value of the new sciences which from time to time have sprung from Astronomy, Astronomy itself in its own particular sphere and by its own discoveries, has triumphantly brought home to us a realisation of relative human values How painful the reflection, and all the more piquant because of its indirectness, does it cast upon our petty earthly squabbles! How small do the great wars and feuds of the past now appear to us—wars which were fought and thrones and kingdoms shattered for an extra slice of territory! And this, too, in a world whose extent of land it would be laughable to call by the name of "territory" in a universe where it is all but a negligible quantity



A SPIRAL NEBULA

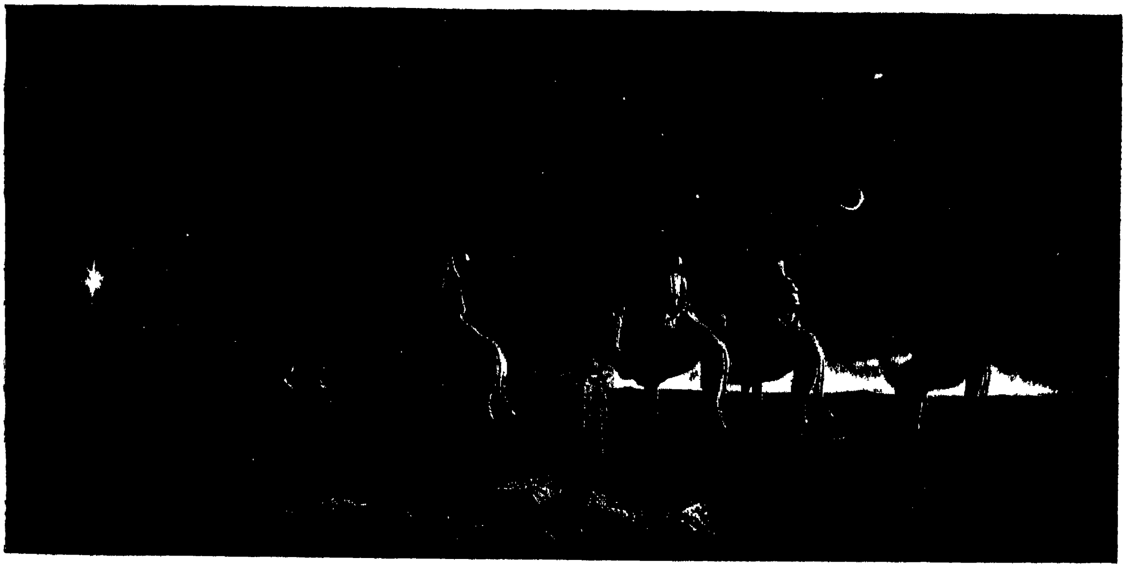
These wonderful celestial whirlpools are found in great numbers in certain parts of the sky, many thousands being known They are composed of diffuse, though not truly gaseous, matter, whose motion has lately been shown to be outwards along the "arms" from the central bright mass or nucleus Here and there this diffuse matter has condensed into small compact masses, and it is believed that spiral nebulæ are destined to end their career by condensing into star clusters Many of these embryo stars are visible in the above photograph

Let us, therefore, be persuaded of loftier interests and reflect on the problem of the cosmos in adequate terms Of all studies, the science of Astronomy is not for the narrow bickerings and carpings of the small mind Feeding as it does the spirit of enquiry, and hallowing it, it is yet within the powers of an ordinary mind to assimilate As has been pointed out, the whole reason for this work is the simple one of initiating the average man into the secrets of heavenly lore It puts within the reach of everyone a means of acquiring what might be called the "necessary knowledge" of Astronomy It will be readily appreciated that there is a border-line beyond which in a work of this description one cannot go But at the same time ignorance of the elements of the subject within the border-line is tantamount to wilful neglect of a golden opportunity for personal development and self-culture The work will not have been undertaken in vain if it is instrumental in commending to the intelligence of its readers an intelligent interest in the spangled vault above



ATLAS.

According to legend Atlas was a member of the older family of gods who bore up the pillars of Heaven The figures on the photograph represent constellations or groups of stars, many of which have been named after animals Cancer (the Crab and Leo (the Lion) can be seen near the top of the globe



THE STAR OF BETHLEHEM

In ancient times the stars were sometimes the sole means of guidance to wandering tribes From the earliest ages they have been the almanacs of uncivilised peoples who studied the face of the sky as an aid to practical life Among civilisations of the past good or evil influences were assigned to the stars

SPLENDOUR OF THE HEAVENS.

CHAPTER I

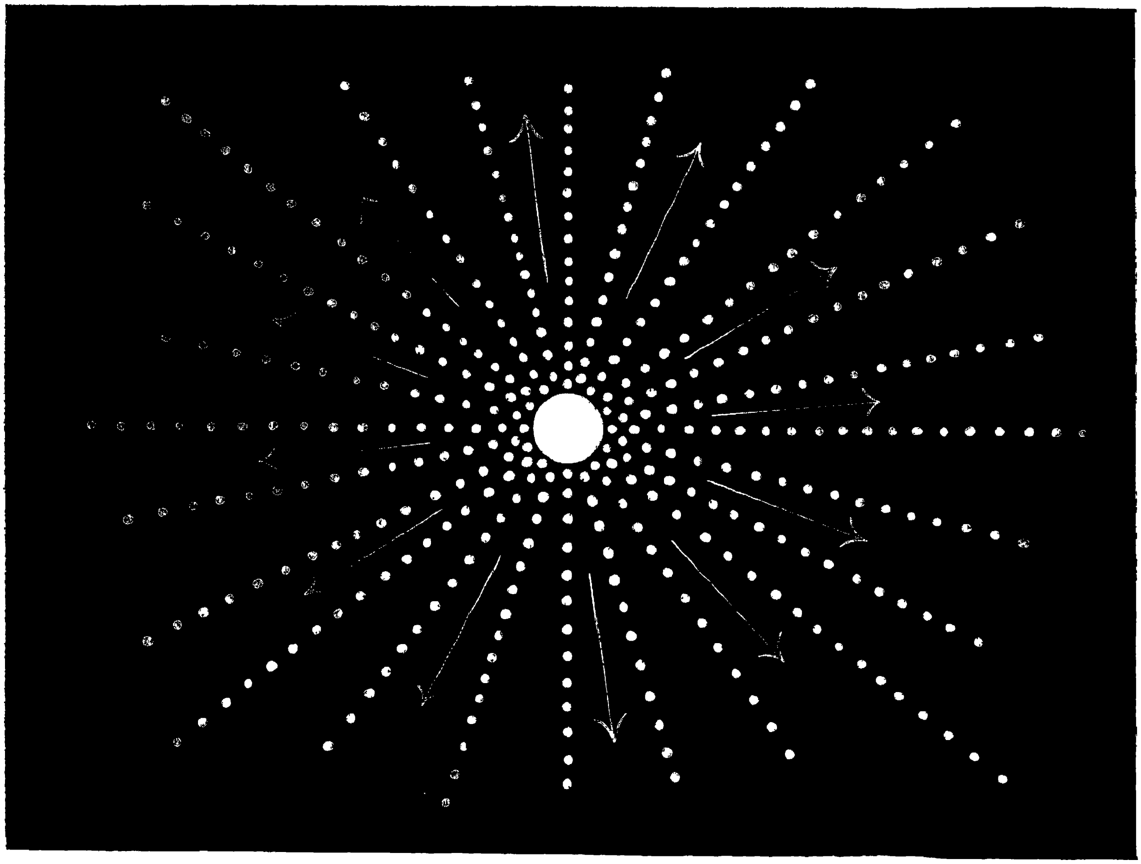
THE STORY OF LIGHT AND MAN'S CONTROL OF IT

BY DR W H STEAVENSON, F R A S

A DISSERTATION on Light and the properties of lenses and mirrors may seem a strange opening to a work on the glories of the firmament And yet such an opening is amply justified by the very nature of Astronomy, for we have to remember that the greatest and most ancient of the sciences differs from all others in one essential particular, which is that it deals with objects altogether beyond our reach We cannot touch, pick to pieces, or analyse them, as is possible with plants, insects, or pieces of rock All our knowledge of them is conveyed across vast abysses of space by that mysterious agency which we call Light The workings of this universal messenger are even now not completely understood, but we have been learning more and more about them during the past three centuries Such knowledge, useful enough in itself, has led us still further, for man has by slow degrees learnt, not only the nature of Light, but also the methods whereby it may be so controlled and harnessed as to deliver faithfully the messages which it conveys

It is quite possible to enjoy a wireless concert without having the least knowledge of the technicalities of radio-telephony On the other hand, there are few people of any intelligence who would not be sufficiently interested to enquire "how it works," even if they pursued the matter no further It is much the same with the revelations of Astronomy The bare facts which are the result of research are easy enough to understand, but a knowledge of how they were obtained greatly enhances their interest for any intelligent person Moreover, the reader is bound, in a work of this nature, to come across certain photographs and illustrations which, if not altogether meaningless, will at least be liable to puzzle and mislead him if he has not learnt some of the methods of the astronomer or the working of the instruments he employs

The nature of Light is a mystery which has exercised the mind of man from the earliest times, and a little thought will show how puzzling the problem was, and indeed still is Here was something



THE OLD CORPUSCULAR THEORY OF THE NATURE OF LIGHT

It was at one time supposed that every source of Light was constantly emitting in all directions myriads of minute particles, which excited the sensation of vision on striking the eye

clearly connected with all visible things of every conceivable nature, yet surely also connected in some way with the observer, since experience suggested that what affects the body must be in contact with it Hence the idea soon arose that Light had a definite concrete existence, was, in fact, a substance But when it came to harmonising such a theory with observed facts, the early philosophers had to resort to the most complicated and fantastic suppositions, none of which was really satisfactory, and which can hardly have been intelligible to the authors themselves It will be enough to say here that out of all this speculation there emerged what is now known as the Corpuscular Theory of Light According to this theory, every luminous body was constantly discharging streams of minute particles in all directions, and these particles, on striking the eye, gave rise to the sensation of Light or Vision This theory had the merit of extreme simplicity, but it unfortunately failed to explain all observed facts It continued, however, to be used as a working hypothesis right up to the last century, when it was replaced by the now universally accepted Wave Theory In this we have an explanation which at least accounts pretty well for all observed facts There are difficulties here and there, but it seems evident that we are very near the truth, and a theory that explains so many things is not lightly to be laid aside

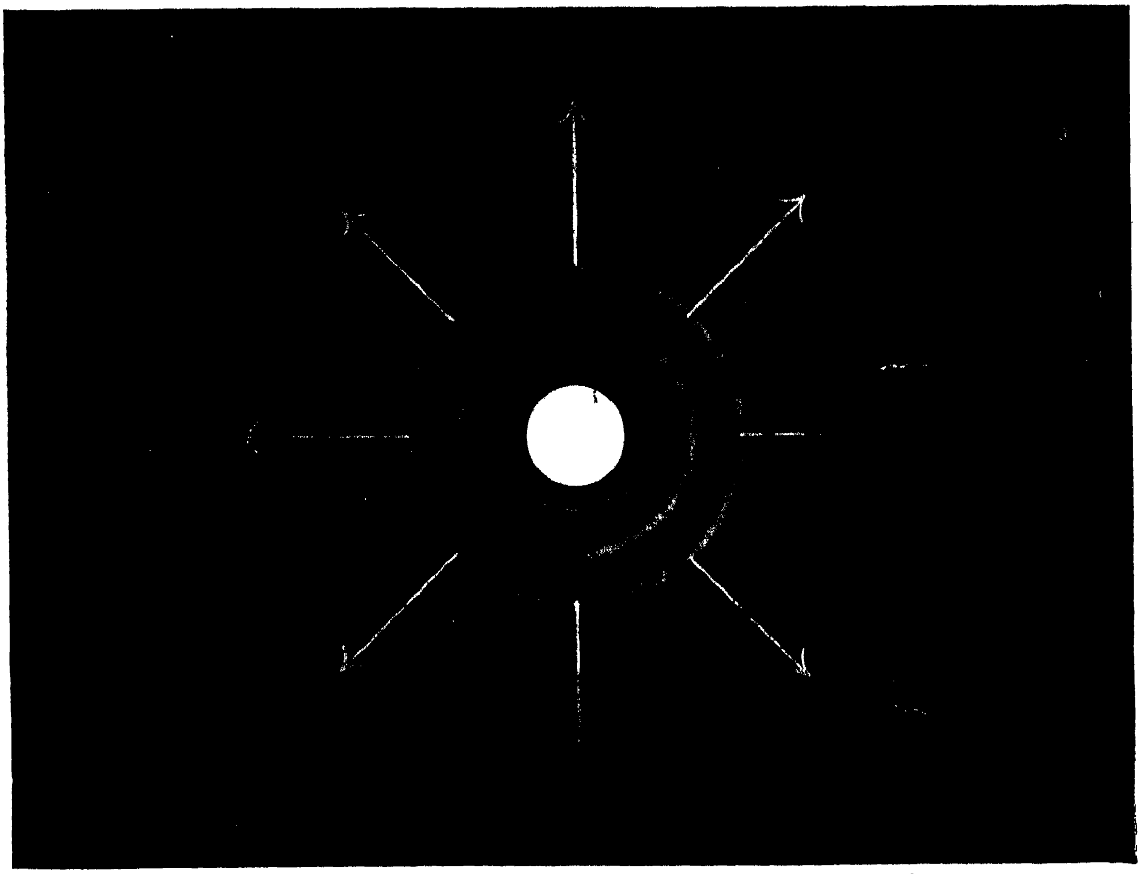
The present theory may be briefly described as follows Light is no longer regarded as a substance, but as a form of energy or motion The minute particles composing a luminous body are in a state of extremely rapid vibration These vibrations set up similar movements or disturbances in that all-pervading Something which scientists call the Ether of Space The disturbances thus set up are in the nature of waves, which move outward in concentric circles from the luminous body, like the

ripples produced when a stone is thrown into still water, except that they do not lengthen out as they advance It is important to remember that it is the waves which move outwards and not the Ether, whose "particles" merely rise and fall as the waves pass, just as a feather will do if thrown on to the ripples in the pond

The Light-waves travel outwards from their source with the prodigious speed of 186,325 miles per second, a distance equal to between seven and eight complete circuits of our Globe Small wonder is it that the early philosophers thought the speed of Light to be infinite! And yet there are bodies visible to us in space whose light takes many thousands of years to reach us Here, surely, is an instance where a knowledge of Light and its properties will help us to a better understanding of the immensity of the Universe

The actual length of a wave of Light, or the distance from crest to crest, is almost as inconceivably small as its speed is staggeringly great The average length is about $\frac{1}{50,000}$ of an inch, and a little consideration will show that, travelling at the speed above mentioned, about 500,000,000,000,000 (five hundred billion) of them must strike the eye every second! But all Light waves, though small, are not of exactly the same length, and it has been found that their dimensions vary according to the colour of the light Thus, the waves of red light are about $\frac{1}{33,000}$ inch long, while those of violet light are nearly twice as short, or about $\frac{1}{64,000}$ inch The eye cannot perceive Light whose waves are longer or shorter than these limits, but such waves can be detected by the photographic plate and other physical means

We can only see a light, or indeed any object, by looking straight towards it, which is another



THE MODERN WAVE THEORY OF THE NATURE OF LIGHT

Light is now regarded as being due to waves in the Ether Every luminous body is supposed to radiate such waves in much the same manner as a stone will do if dropped into a pond, but with a velocity of over 186,000 miles per second The distance from crest to crest determines the colour of the Light as seen by us

way of saying that Light normally travels in straight lines This may seem a contradiction of what has already been said of the circular arrangement of the Ether-waves round a luminous body, but we have to remember that it is the *direction* of motion and not the *shape* of the waves that is straight Therefore we may and do imagine Light as issuing from a bright point in an infinite number of straight lines, arranged like the spokes of a wheel The actual waves are moving outwards along these "spokes" and always at right angles to them Any one of these spokes may, for the sake of simplicity, be considered separately, and is then referred to as a "ray" Such a way of looking at Light makes simple the explanation of optical instruments, and we shall often have occasion to use it in what follows

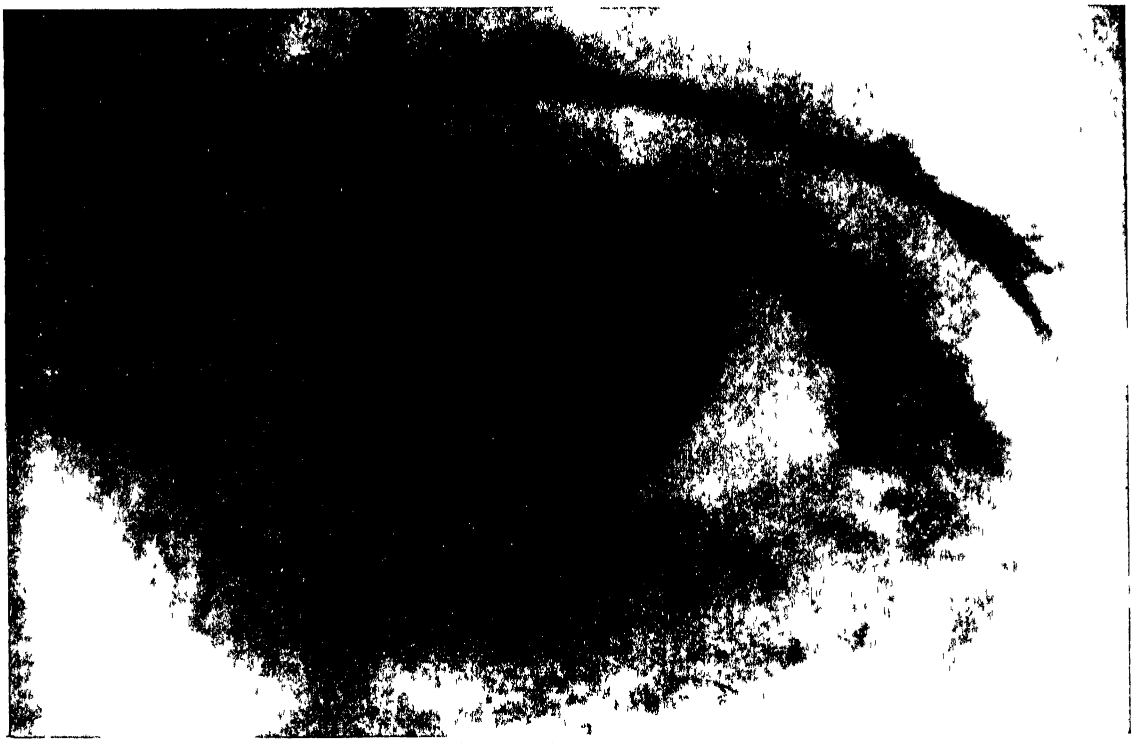
So far we have only dealt, very briefly, with the supposed nature of Light as it travels unfettered through Space We shall now turn to the methods whereby man has learnt to handle and control these mysterious ripples of the Ether, to the great increase of his knowledge of the Universe

A FAMILIAR PROOF OF A GREAT TRUTH

A ray of light, if looked at from one side, is itself invisible, but particles of dust may be lit up by it and then mark the path of the ray Such paths are never curved, and thus we learn that unfettered Light always travels in straight lines

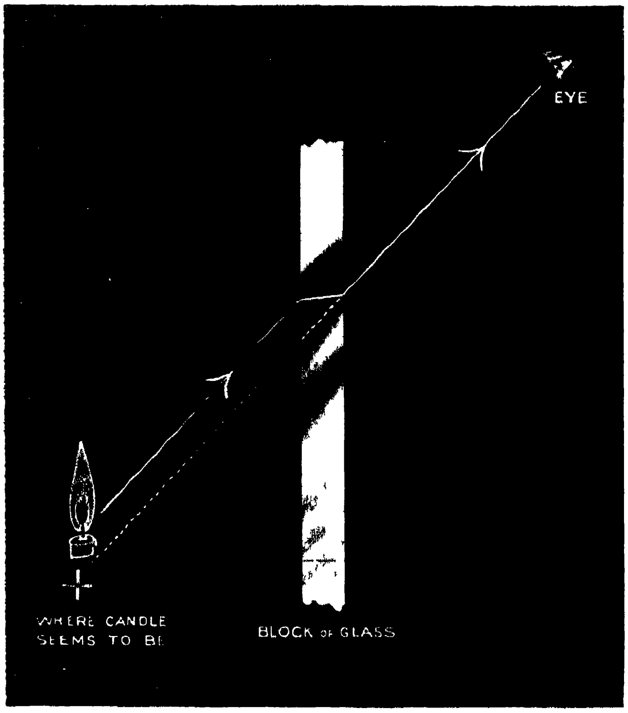
It was long ago observed that stones at the bottom of a shallow pool appeared from the bank to be displaced from their true positions so as to seem nearer to the opposite bank than they actually were Moreover, it was noticed that, when ripples were present on the surface of the water, the shape as well as the position of the stones was altered and distorted We may observe the same sort of thing by looking obliquely at some object through a piece of plate glass If the latter is good, the object will merely appear bodily displaced, but if the glass is "wavy" it will also alter the outline of the object What is really happening will be clear from our illustration The light by which we see the object has not travelled straight towards us This does not mean that it has travelled

THE EYE IN DAYLIGHT



THE EYE AT NIGHT

Light can only enter the eye through the pupil, whose size is automatically controlled according to the requirements of vision When Light is abundant the pupil is small, as in the top illustration, but at night it enlarges to admit as much Light as possible, as in the lower illustration, which was taken by flashlight in a darkened room The flash lasted only a small fraction of a second and was over before the pupil had time to contract in response to the sudden glare



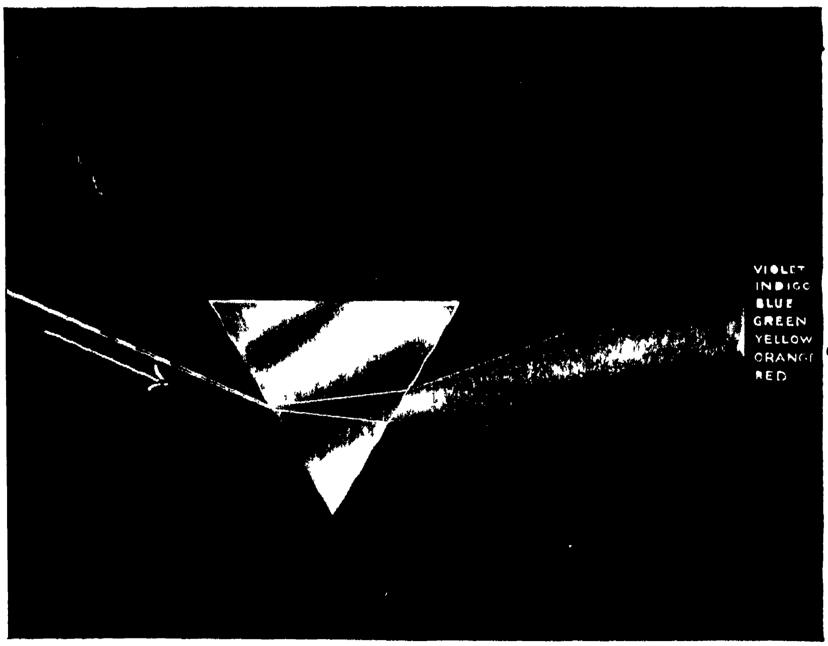
TURNING A LIGHT RAY FROM ITS PATH

When a ray of Light falls obliquely on a piece of plate glass or similar transparent substance, its direction is altered, and an observer on the other side of the glass sees the source of Light displaced from its true position This bending of Light is known as Refraction

in a curved path, but that its straight path has "had its back bent," as it were, at one or more places This bending of Light is known as Refraction, and it always occurs when a ray passes at an angle from one medium (such as air) to another that is either more or less dense The amount by which the Light is bent depends on the density of the substance through which it passes, but the final direction of the ray depends not only on this, but also on the shape of the surface of the substance This is why rippling water or "wavy" glass will give different directions to rays coming from different parts of an object, and thus produce a distortion of its shape This brings us at once to that greatest and most fundamental of all optical inventions—the Lens

A lens is a piece of glass or other transparent substance which has had its surfaces deliberately shaped by the optician in such a way that rays passing through it shall be turned as far as possible in certain desired directions We have no knowledge of the exact date when lenses were first made, but we know that they were in existence at the end of the Thirteenth Century, and that they were then in use, as to-day, for spectacles

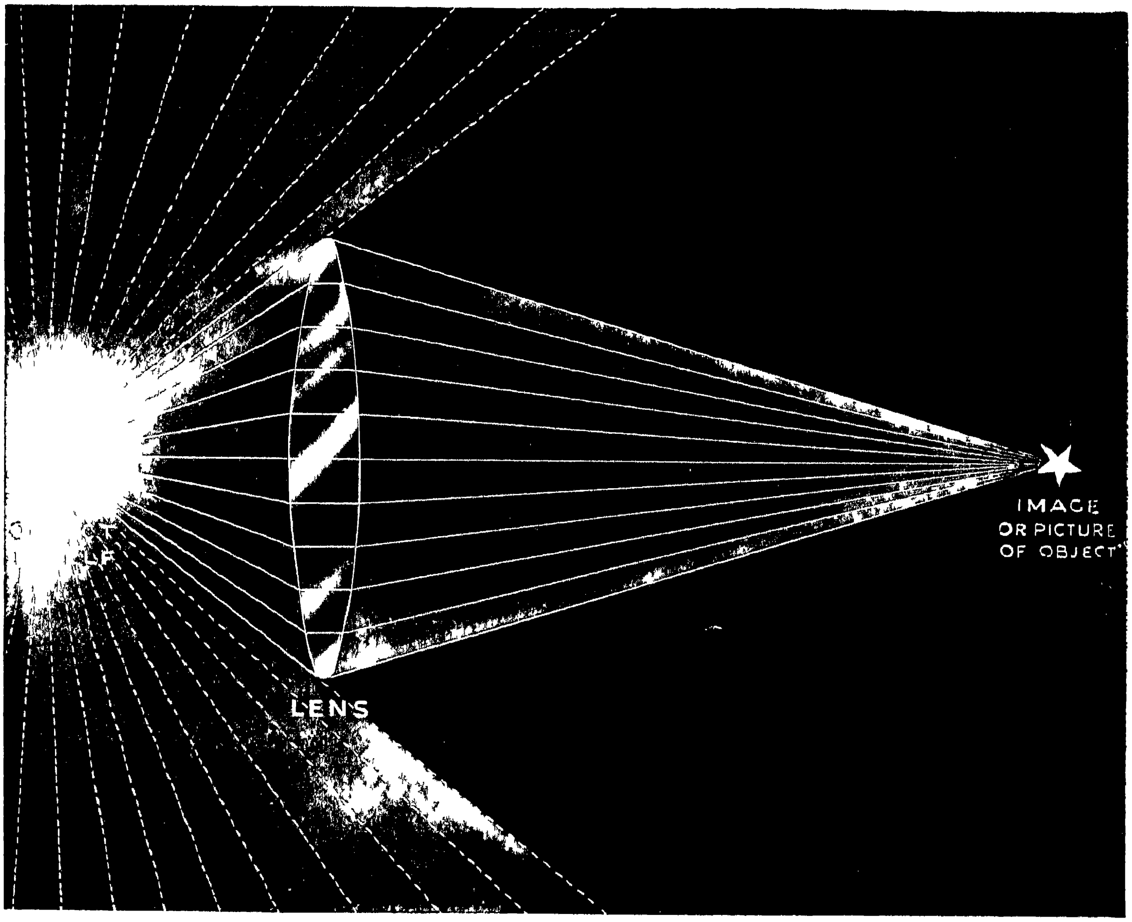
Lenses are, broadly speaking, of two kinds—positive and negative The first type are thickest in the middle and tend to bring together the rays which pass through them The second type are thickest at their edges, and tend to spread out the rays In practice the two types are often used in combination, the nett result on the rays depending mainly on the relative "strength" (*i e*, thickness



A RAY OF LIGHT "DISSECTED"

A prism, or piece of glass of triangular section, treats rays of different colour unequally White Light is composed of rays of all colours, which are separated out on passing through a prism The violet rays are bent most and the red least This spreading out of a narrow white ray into a fan of many colours is called Dispersion Newton was the first to explain the action of a prism

or thinness) of the various lenses Let us now consider the case of a single positive lens, of which an illustration will be found below Here we have a piece of glass whose surfaces are both curved, and it will be noted that, unlike the case of plate glass, these surfaces are inclined towards one another at every place except the exact centre of the lens, where they are parallel The result of this inclination is that the rays, which are bent on entering the glass, are not restored to the same general direction on leaving it, but are *bent still further* The same thing happens to all the rays, though an examination of the diagram will show that the bending effect grows less and less towards the centre of the lens, where it ceases altogether and the rays pass straight through By carefully fashioning the surfaces of such a lens we can arrange to make all the rays from one point (the object) meet together at another point on the opposite side of the lens In this way we have, as it were, created in space



HOW A LENS WORKS.

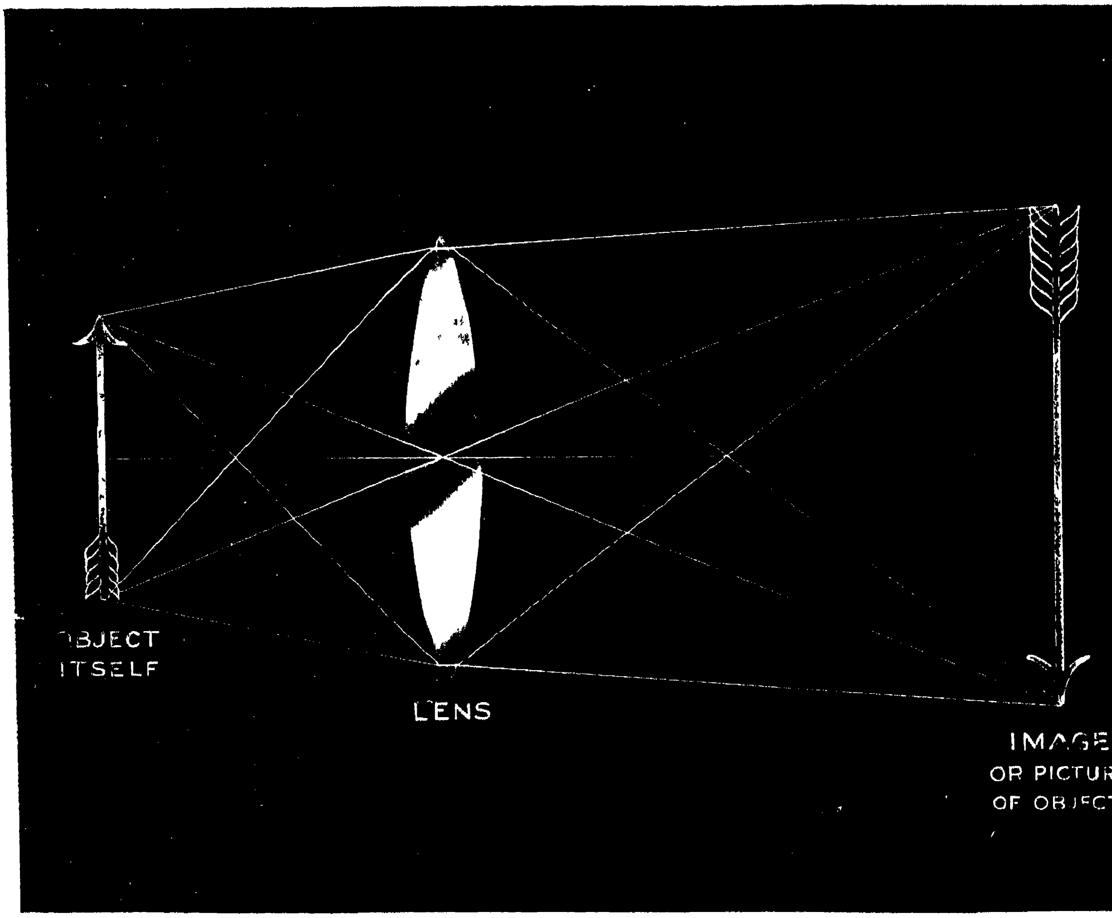
When Light rays from a point strike a piece of glass with curved surfaces, known as a lens, each ray suffers a slightly different deflection, and a lens can be so fashioned that all the rays will meet again at a point on the other side

a ghostly counterpart of the original object, which it will exactly resemble so far as its light, or visibility, is concerned Such a "ghost" is known to scientists as an "image"

So far we have only considered the rays from a single point, but the case is just as simple if we take two, or even three points, for each one will have its image produced separately in space on the other side of the lens Now, an object of any size, such as an arrow, may be considered as consisting of a very great number of separate points, each of which will have its corresponding image

Thus we can readily see that a complete picture of the object will be formed by the lens, and if we trace the path of the rays with the aid of a diagram we shall find that the picture is always upside down as compared with the object

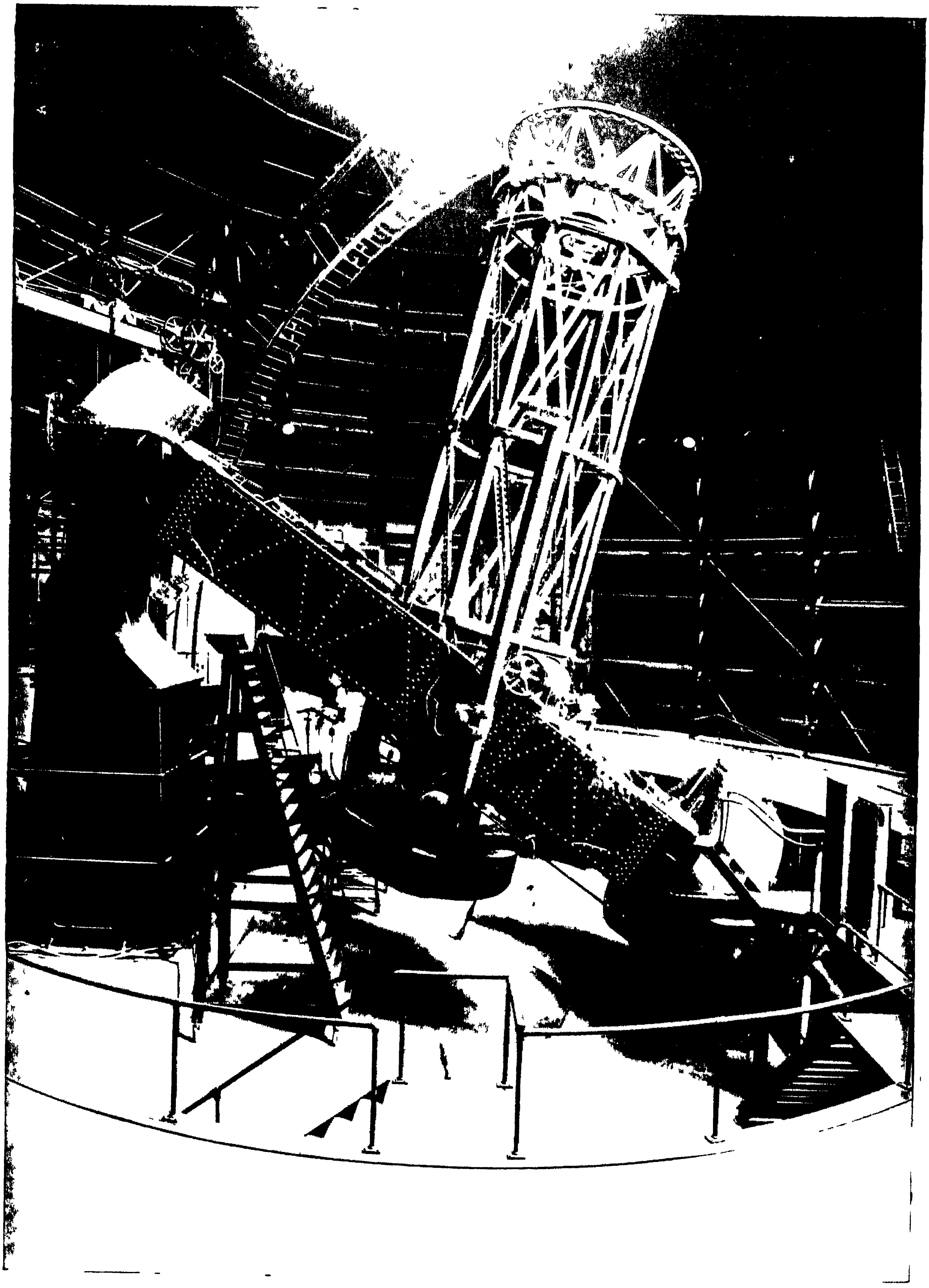
In thus forming artificially a light-picture or image of an object, it may not appear that a lens has done us much service, but it is really upon this action that our power of distinct vision entirely depends In the human body all sensations are conveyed to the brain by means of fine filaments called nerves, some of which convey one kind of sensation and some another Those which give rise to the sensation of Light are exceedingly numerous and are entirely confined to the two eyes There



MAKING LIGHT PRODUCE A PICTURE

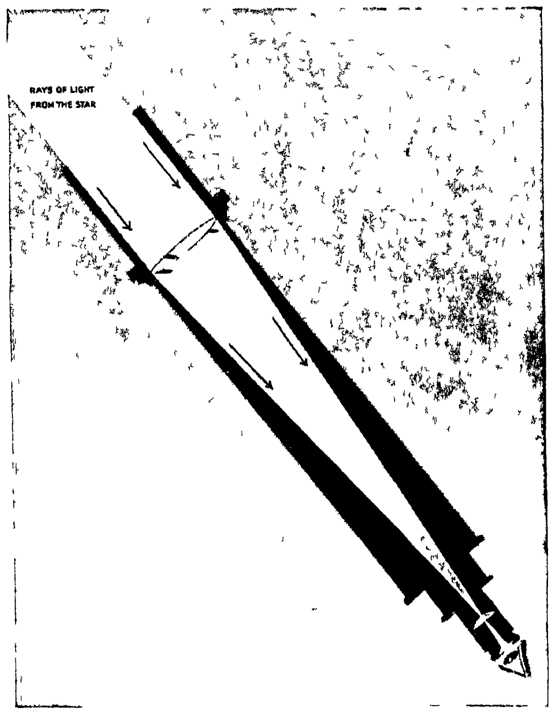
Our illustration shows how the rays from a large object are treated by a lens Every point of the object has its counterpart on the other side of the lens, as shown in the previous illustration, and thus a complete picture (generally called an image) is formed in space where the rays converge It will be seen that such an image is always upside down

the delicate endings of the nerve filaments are closely packed together, like the pile of a carpet, so as to form a continuous inner lining to the back of each eye-ball Light from external objects reaches this nervous lining (called the "retina") through a small aperture of variable size, known as the pupil, and the impression of luminosity is straightway conveyed to the brain But there is more in vision than this If the above description of the eye were complete, then light from every part of an object would strike every part of the retina, and the confusion resulting would leave us in ignorance as to the true direction of the various rays, in other words, we should have no knowledge (from vision alone) of the *form* of objects, but merely be conscious of their *brightness* This is where



THE MOUNT WILSON TELESCOPE

This giant instrument is the largest telescope in the world It shows millions of stars that are too faint for other instruments Its tube is ten feet in diameter and forty three feet long, the great 100 inch mirror being mounted at its lower end It has been constructed to deal with problems unsuited to telescopes of inferior power The site of the Mount Wilson Observatory was chosen with a keen eye to favourable atmospheric conditions It is 5,900 feet above sea level



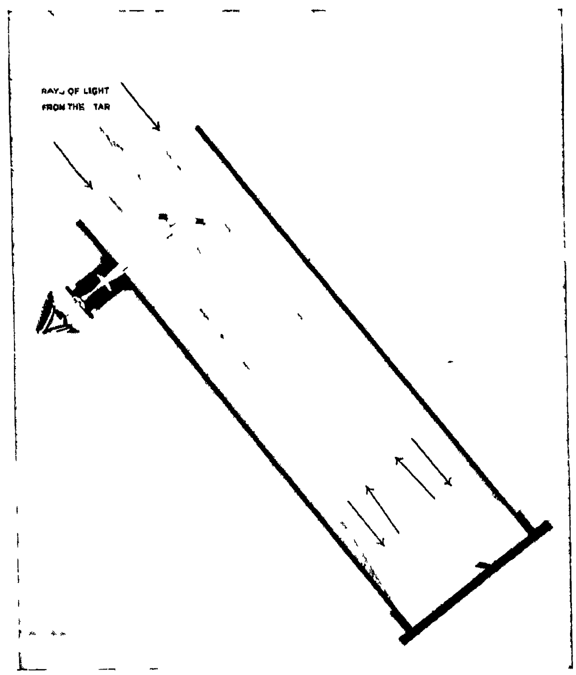
SIMPLE REFRACTING TELESCOPE

A picture of a distant object, formed by a large lens as explained above, is magnified by a smaller lens, called an eye piece It will still appear upside down, but this is no disadvantage to the Astronomer In terrestrial telescopes additional lenses are inserted to erect the image

that the *size* of the picture is also greater, as well as its distance from the lens In other words, the greater the focal length the larger the picture Now the lens of the eye is very much thicker in the middle than at the edges, so its focal length is small In fact, it forms its picture less than an inch from its back surface The result of such a small distance is that every object in a landscape is seen very small, though a great width of view is included in the picture If we desire to obtain a larger view of any one object we have only to approach it and thus make it appear, within certain limits, as large as we like But the case of the astronomer is different He cannot get appreciably nearer to the heavenly bodies than he is at present, so that, using his eye alone, he has to be content with a very small picture of them

The second great defect of the eye, from the astronomer's point of view, is the smallness of its opening—the pupil This has nothing to do with the size of the picture formed in the eye, but it has everything to do with its brightness When the lens comes in, for we have seen that it has the power of dealing separately with individual rays, and putting them all in their right places without confusion Every eye contains a lens, not of glass, but of a transparent horny substance, and this lens throws its pictures on the retina of the eye Here each part of the image will affect a different filament of the "pile-carpet," and all these impressions will be conveyed separately to the brain, where the form or shape of the object will be thus revealed

Thus we carry about in our own bodies the most ancient of all optical instruments, and a very efficient one too, for most purposes of everyday life But to the astronomer it has two great defects The first is the smallness of the pictures produced by it This is due to the small scale on which the eye is constructed If we experiment with different lenses, thin and thick, we shall find that the thin or flattish ones produce their pictures of a distant object much further from the glass than the thick ones do, and they are therefore said to have a greater "focal length" But this is not all, for we shall notice

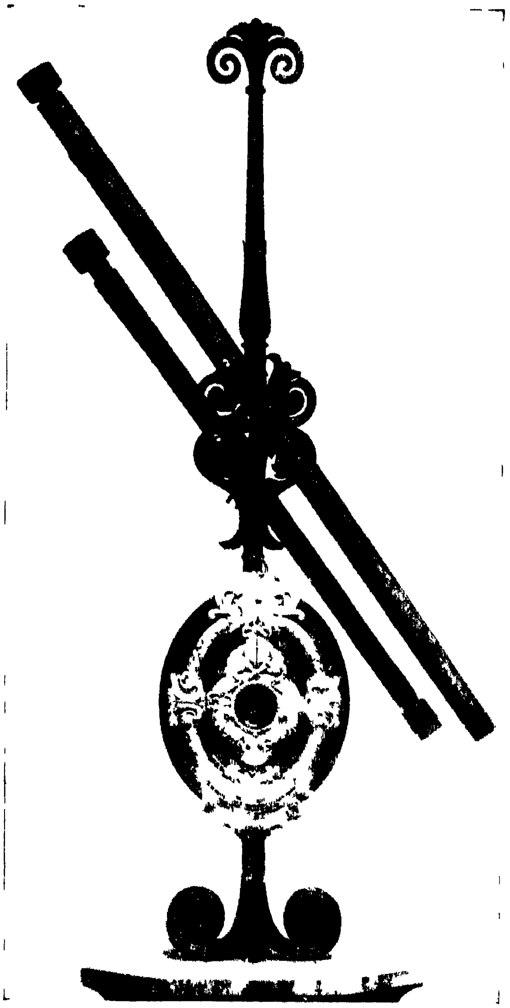


PRINCIPLE OF NEWTON'S REFLECTING TELESCOPE

A concave mirror made of metal or glass will form a picture of a distant object by reflection, the rays being controlled in their directions as in the case of a lens The image is formed at the side of the tube (by interposing a small flat mirror placed obliquely), and is there magnified by an eye piece

we remember that a star, or distant light, is sending out rays in all directions we can readily see that only a minute proportion of these rays can enter such a small thing as the pupil, and that this proportion becomes smaller and smaller as our distance from the light increases. The result of this is that a very distant or very faint light fails to send us enough rays to make it visible, and we see nothing at all. Nature does her best to help us in this direction, for when the light of surrounding objects is feeble, as at night, the pupil automatically enlarges to take in more rays. But obviously there is a limit to this enlargement, and it never exceeds about one-third of an inch.

Thus the early astronomer felt the limits of the power of his eye and cried out for two things—a bigger picture and more light. What he needed, in fact, was a larger eye than the one he had, one



GALILEO'S TELESCOPES

With the construction of these little instruments, in 1609, the telescopic revelation of the heavens began. The first discovery made was that of Jupiter's moons, followed by the Mountains of the Moon, the Starry structure of the Milky Way, and, in 1611, the phases of Venus, the Spots on the Sun, and the strange appendages of Saturn. Such telescopes would be considered very feeble instruments nowadays, but they had a profound influence upon the History of Astronomy and revealed many wonders for the first time.

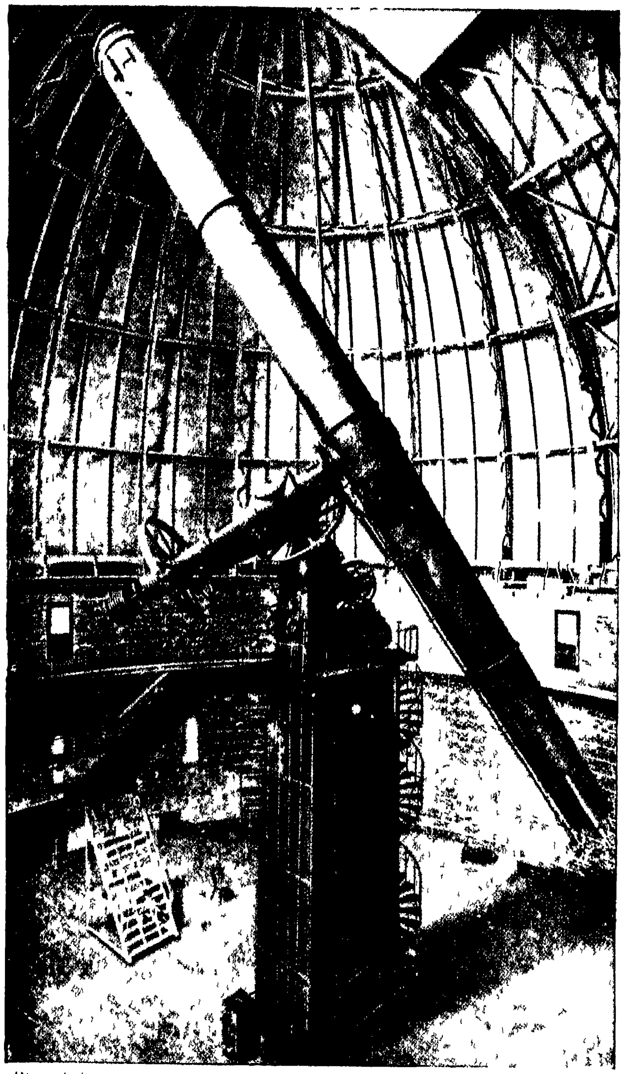


Photo by] [*The Yerkes Observatory*

THE GREAT YERKES TELESCOPE

Of 40 inches aperture, this telescope was mounted in 1897 at Chicago University Observatory. It is the most powerful refractor yet constructed, and is housed in a massive brick tower 90 feet in diameter. Its tube is 64 feet long. The total weight of glass in the two lenses—which together form the object glass—is 500 pounds. These lenses are of extraordinary purity and transparency, yet they absorb much light because of their great thickness. The moving parts of the telescope weigh over 20 tons. It has been used chiefly for spectroscopic work and for the observation of double stars, these being branches of work for which its great aperture and focal length render it specially suitable.

that should be longer—to produce a larger picture, and one that should have a wider opening—to admit more light And this is exactly what he obtained by the invention of the telescope

Every telescope is, in principle, a reproduction of the human eye on a larger scale It will be clear from what has gone before that any lens whose diameter is more than $\frac{1}{3}$ of an inch, and whose focal length is over an inch, will produce a picture in space that is brighter and larger than that formed in the eye However, it may not *appear* so large at first sight, because we cannot approach it closely and still see it distinctly But a lens whose focal length is over about ten inches will form a picture that looks perceptibly larger than the object itself, viewed without the lens This must have been noticed in the early days of lens-making, and yet no use appears to have been made of it

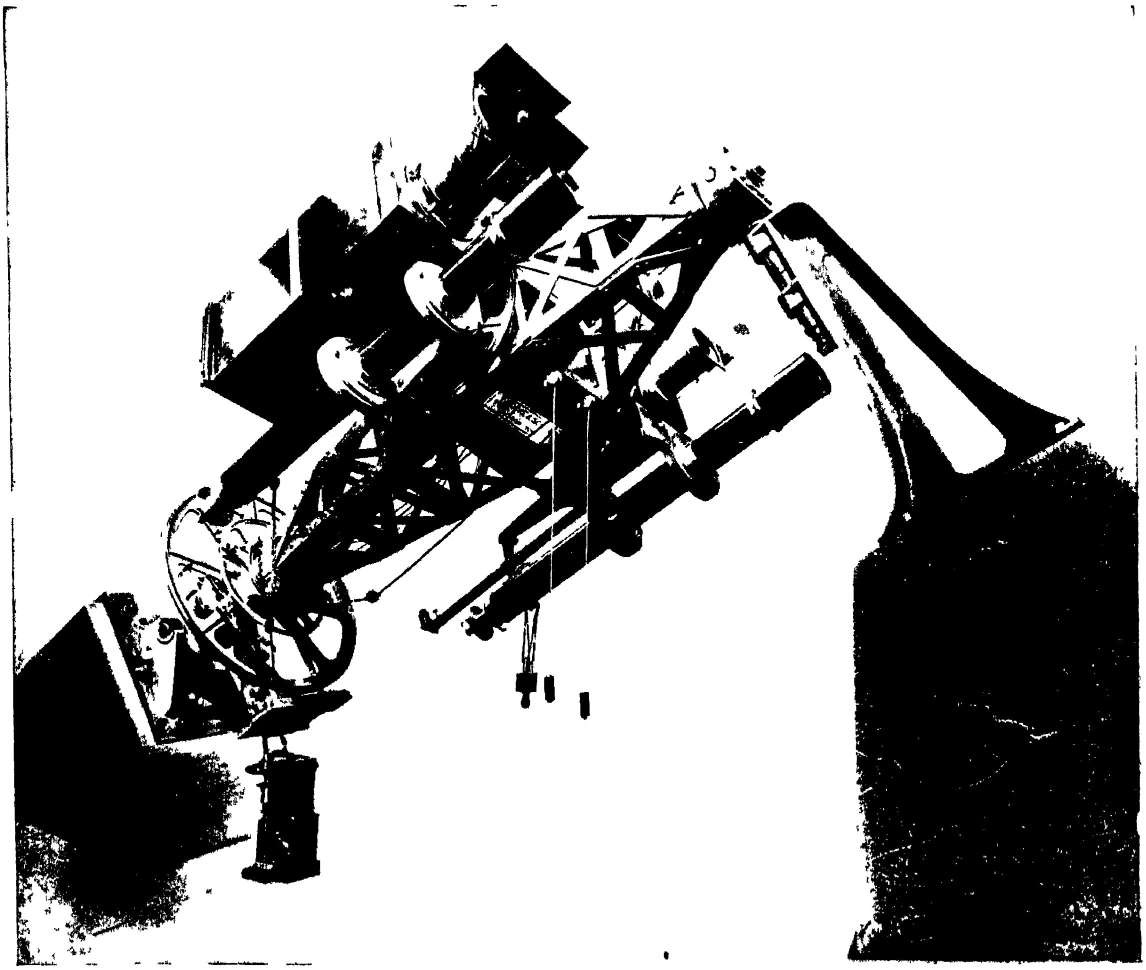


Photo by permission of] [*The Royal Astronomical Society*

A STAR-CAMERA MOUNTED FOR PHOTOGRAPHING THE HEAVENS

With an instrument of this type large areas of the sky can be photographed on a comparatively small scale The Camera is mounted on an axis which turns by clockwork to follow the stars in their apparent march across the sky The telescope attached is pointed in the same direction as the camera and enables the astronomer to see that the clockwork is keeping the whole instrument accurately pointed in the same direction throughout the time of exposure

until the beginning of the Seventeenth Century It was then observed by Hans Lippershey, a Dutch spectacle maker, that, by the insertion of a second lens between the eye and the image, it was possible to get much nearer to the latter and so obtain an enlarged view This was much more convenient and effective than the use of a single lens of very long focus, and besides, by using eye-lenses of different strength, varying degrees of magnification could be obtained without changing the "object-glass," as the lens was called which formed the image

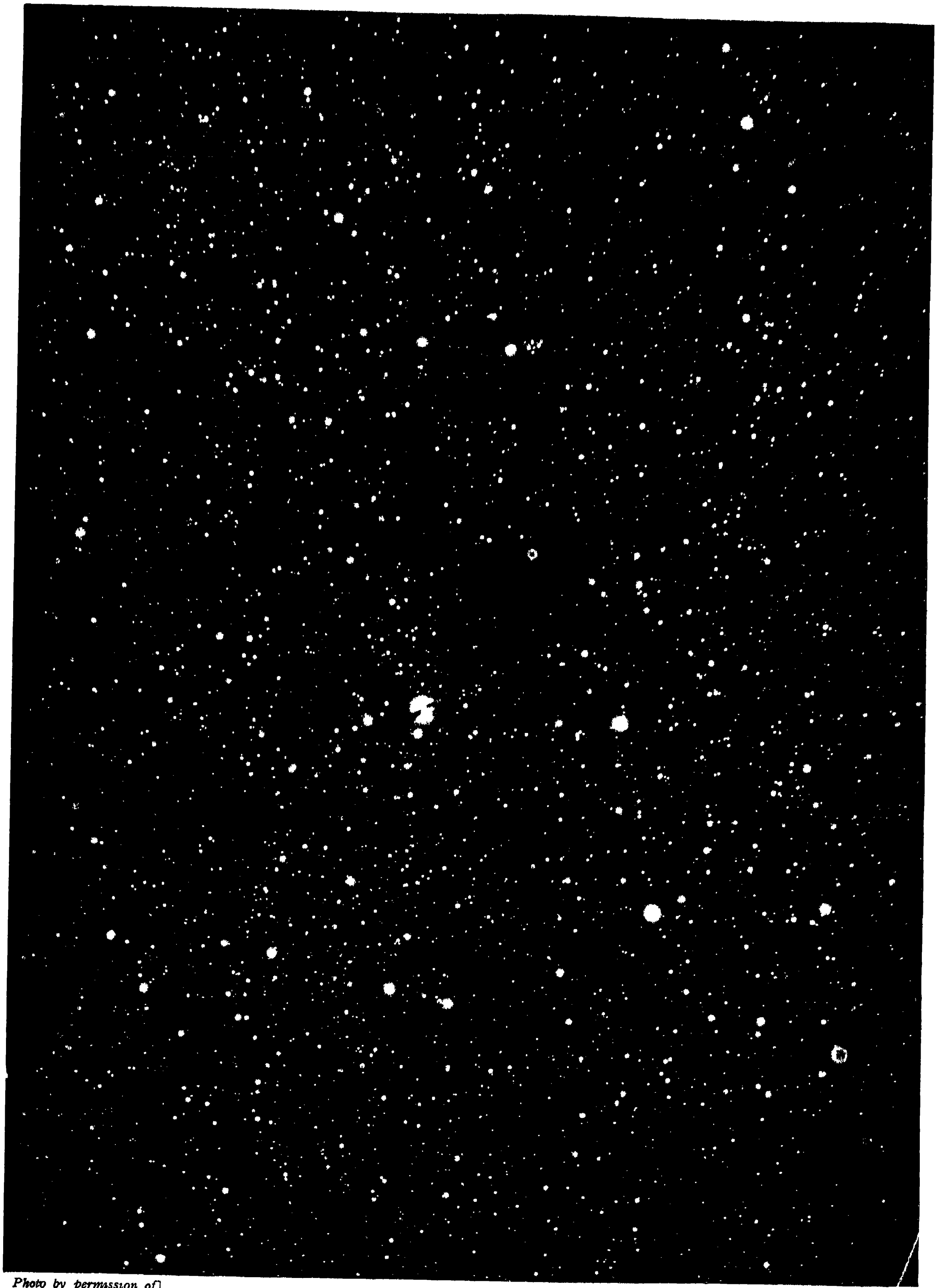


Photo by permission of] [*The Royal Astronomical Society*

A STAR CHART PRODUCED BY PHOTOGRAPHY

A Star Camera of the kind shown in the last illustration produces a chart of the Heavens similar to the above. Many thousands of stars are automatically and correctly recorded in a single hour. It would take years to map the same number of stars by visual means, and even then errors would be certain to occur.

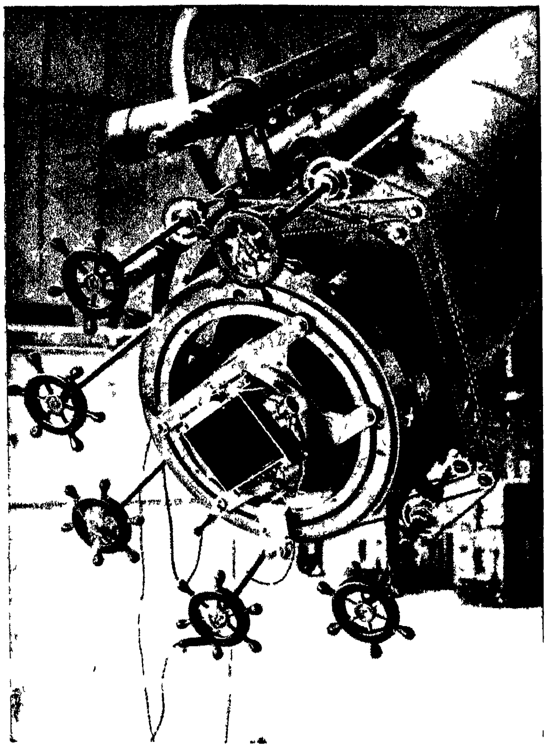


Photo by] [*The Yerkes Observatory*

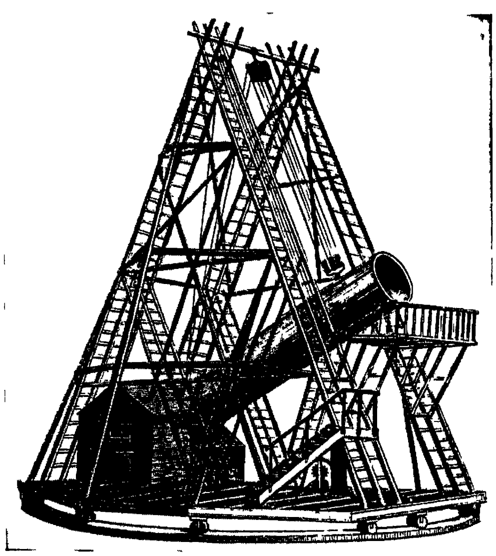
A GREAT TELESCOPE CONVERTED INTO A CAMERA

When it is desired to photograph small portions of the sky on a large scale it is necessary to use a very long telescope. One has only to remove the eye-piece and substitute a photographic plate to receive the image formed by the great lens. Our illustration shows the 40 inch Yerkes refractor converted in this way.

Lippershey was not an astronomer and it does not seem to have occurred to him to apply his new invention to the study of the heavens. In fact, he only saw in it a discovery of great military importance! But news of it reached Galileo, the Italian astronomer, in the year 1609, and he was able, without having seen a specimen of the new instrument, to construct one himself from the description alone. The construction adopted by Galileo was almost identical in principle with that in use by astronomers to-day, except that the eye-piece was a negative lens. This form of telescope, however, has still survived in the modern opera-glass, which is often referred to by opticians as the "Galilean," to distinguish it from the prism binocular. Galileo made several telescopes, but the largest was scarcely more than an inch in diameter, and magnified less than forty times. Compared with our modern astronomical telescopes it was, of course, a mere toy, but, for all that, it was a very great advance on the unaided eye.

Now were revealed to man for the first time the mountains on the Moon, the satellites of Jupiter, the phases of Venus, the starry background of the Milky Way, and the shapes of the spots on the Sun. But as yet these things were very imperfectly shown, and it became clear that nothing much more could be done until the new instrument was greatly improved and enlarged. Unfortunately, this was by no means a simple matter. The making of discs of glass good enough to turn into lenses demands, even to-day, a great deal of care and skill, except for those of very small size; it can well be imagined that three hundred years ago the problem was an extremely formidable one. In fact, a full century after Galileo's pioneer work it was difficult to produce a good lens that was more than two or three times the size of the ones he used. Moreover, another difficulty was encountered which was really the more serious of the two.

It had been noted from the most ancient times that beautiful colours were seen when white light passed through pieces of glass or precious stones whose surfaces were inclined to one another. In fact, the "cutting" of diamonds and glass was specially designed to produce such "rainbow" effects. It was not until the end of the Seventeenth Century that the true explanation of these colours was given by Newton,

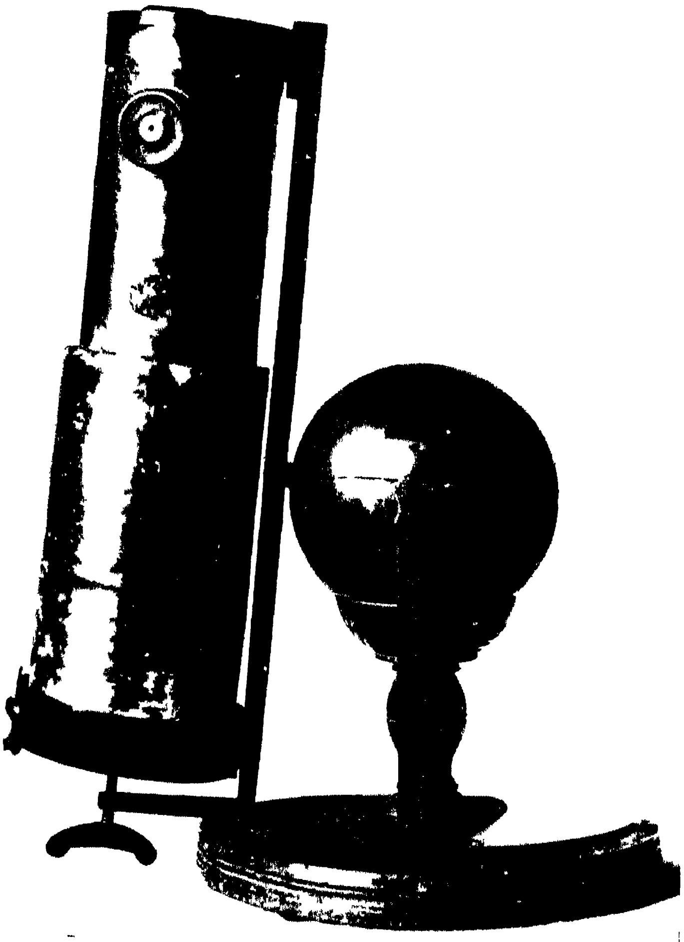


HERSCHEL'S GREAT 4 FOOT REFLECTOR

This instrument, a prodigy in its day, was erected at Slough by Sir William Herschel in 1789. It penetrated into space far beyond the limits reached by any telescopes before it.

who showed that they were the natural consequence of breaking up white light, whose whiteness was simply the combined effect on the eye of a great number of different colours. By causing a narrow beam of white light to pass through a triangular piece of glass, called a "prism," Newton demonstrated that the beam was not only deflected (*i.e.*, refracted) as a whole, but was also spread out into a coloured band. This spreading out of white light, called "dispersion," was due to the fact that the prism bent each coloured ray by a slightly different amount, the violet ones most, and the red least of all. We shall see later that this dissection, or picking to pieces, of white light was destined to be of tremendous importance and value to astronomers, but at present we are most concerned with the embarrassment it caused in the Seventeenth Century to the would-be improvers of the telescope.

A prism seen in section has a thick base, and its two sides are inclined so as to meet at a point, completing the triangle. Now, the big lens of a telescope is thick in the middle and its surfaces taper to a point in either direction; so it can be considered as being equivalent to two prisms, placed one on top of the other with their bases together. It is clear, then, that with such an arrangement rays of different colour will suffer a different amount of bending. Thus a picture of a violet will be formed nearer the lens than one of a geranium because the violet rays are more strongly bent than the red. This would not matter much if every object was of one colour only. But we have seen that *all* colours are contained in white light, so that we shall have a regular string of pictures of a white object, each one of a slightly different hue. If we try to look at such a picture from behind (as we do with a telescope) we shall see all these coloured images one behind the other at different distances from us. The result is a chaotic mixture of colours, in the midst of which is an indefinite watery-looking picture of the object we are trying to examine.



By permission of] NEWTON'S HOME-MADE TELESCOPE [*The Royal Society*

This little model was made by Newton to demonstrate the efficiency of an instrument designed on the lines which he had laid down. It was too small to be of much practical use, but it was the forerunner of all the giant reflectors of modern times. It is now in the possession of the Royal Society.

This, then, was the great drawback to the construction of good refracting telescopes, and it was not overcome for a hundred and fifty years. It was minimised to some extent by making telescopes extremely long (sometimes several hundred feet), since this had the effect of spreading apart the coloured images and thus causing them to interfere less with one another. Instruments of this kind were very unwieldy and difficult to mount, but there seemed no other way out of the difficulty.

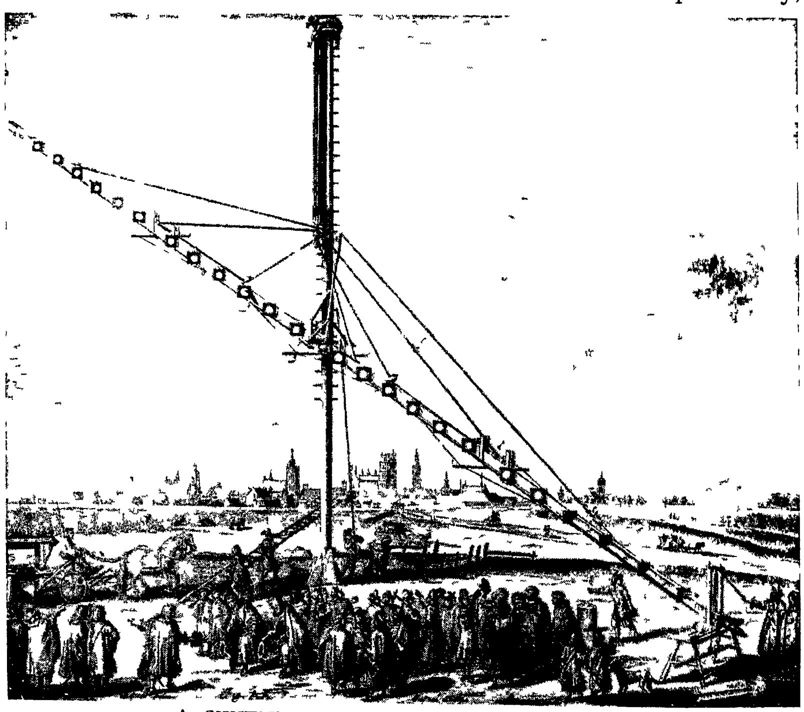
Photo by] 100 INCH MIRROR [E N A

The principal mirror of the recently made Hooker Telescope at Mount Wilson is made of glass, 13 inches thick and over 100 inches in diameter Its slightly concave upper surface is coated with an exceedingly thin layer of silver deposited chemically Its great weight (4½ tons) made it very difficult to mount, but this was successfully accomplished, and the completed telescope is the most powerful in the world The great mirror collects at least 100,000 times as much light as the unassisted eye (In the illustration most of the mirror is covered with cotton wool)

The situation was only saved by the introduction of an entirely different principle in the construction of telescopes

The old troubles had all been caused by the light having to pass *through* glass lenses If rays could only be bent by some other method, all would be well As a matter of fact, such a method was not far to seek, for curved mirrors had long been known to have the property of bending rays of light by reflection, and they had been for centuries in use by alchemists as substitutes for burning-glasses Unfortunately, however, their surfaces were curved in such a way as to prevent them producing really clear pictures such as the astronomer needed But the problem was solved by Hadley, who was the first man to demonstrate practically, in 1723, that the surface of a mirror could so be shaped as to form a clear image of a distant object by reflection, moreover, this image was entirely free from the confusing colours produced by the refractor Many years before this Newton had actually made a small reflecting telescope, though with the mirror wrongly curved It only needed improvement to the mirror to complete its efficiency, and its general principle was the one adopted by Hadley

The new type of telescope was not developed so rapidly as might have been expected from its merits of performance and simplicity of construction, but, towards the end of the Eighteenth



A SEVENTEENTH CENTURY TELESCOPE

In order to minimise certain defects of the Lenses then in use it was necessary, in the Seventeenth Century, to make Telescopes of enormous length These were very difficult to mount and use

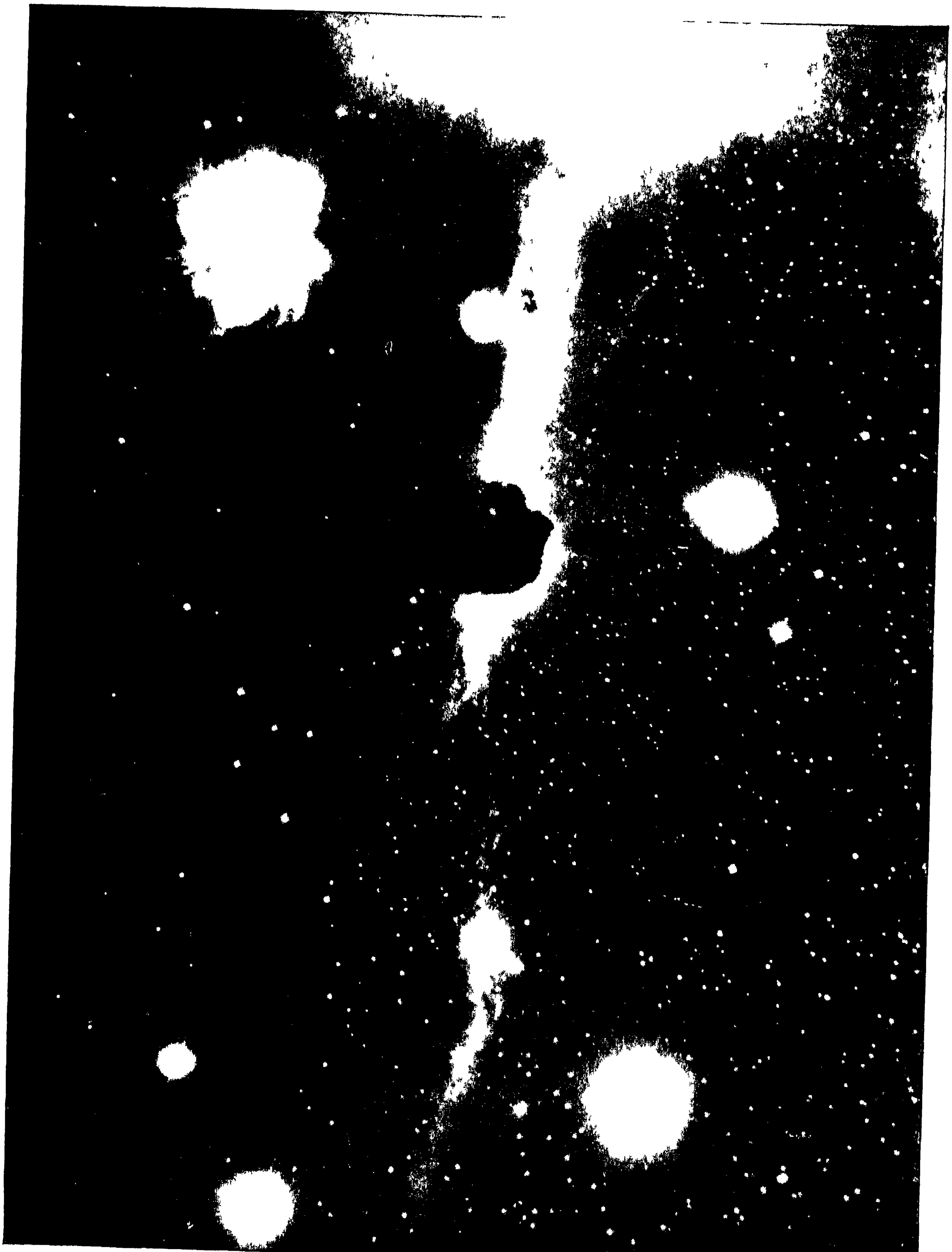


Photo by permission of] [*The Royal Astronomical Society*

HOW THE CAMERA TRIUMPHS OVER THE EYE

This delicate veil of nebulous matter, situated near Orion's Belt, is quite invisible to the eye in the largest telescope. But for the photographic plate it would probably have remained for ever unknown to us. During long exposures, often lasting many hours, the plate accumulates impressions and stores them up in its sensitive surface, whereas the eye sees only what is bright enough to affect it immediately, and rather loses than gains by protracted gazing.

Century, William Herschel began to make really large instruments on the Newtonian principle Starting with mirrors of about six inches diameter, he ended by making one that was no less than four feet across This great access of telescopic power placed him in a unique position among his contemporaries, and he made the fullest use of it Since his day still larger reflectors have been made, culminating quite recently in the gigantic telescope of the Mount Wilson Observatory, whose mirror is just over 100 inches, or more than eight feet in diameter Up to the middle of the Nineteenth Century, telescope mirrors were made of metal, an alloy of copper and tin being used This material was, however, very liable to tarnish, and repolishing was a difficult and delicate undertaking In the present day the mirrors are made of glass, on the *face* of which a thin film of silver is deposited chemically This film is liable to tarnish, but can easily and quickly be renewed when it does so

We must now return to the refracting telescope, in which great improvements had been made while Herschel and others were developing the reflector An Englishman, Chester Moor Hall, had suggested that, by combining two kinds of glass, rays of nearly all colours could be brought to practically the same point, and another Englishman, John Dollond, was the first (in 1758) to make this generally known The telescopes which he made, though quite short, were found to give images comparatively free from false colour, and were a vast improvement on the ungainly monsters of the Seventeenth Century Meanwhile, also, the making of optical glass was being rapidly developed, especially in Switzerland and France, and early in the Nineteenth Century telescopes of Dollond's type reached a diameter of eight or ten inches Such instruments were known as "achromatic," that is, "free from colour" Still better results have of late years been obtained by the use of three lenses, but object-glasses of this type are very expensive, and the ordinary two-lens combination of Dollond is, with slight modifications, the one usually employed to-day Glasses of this kind have been made in all sizes up to forty inches

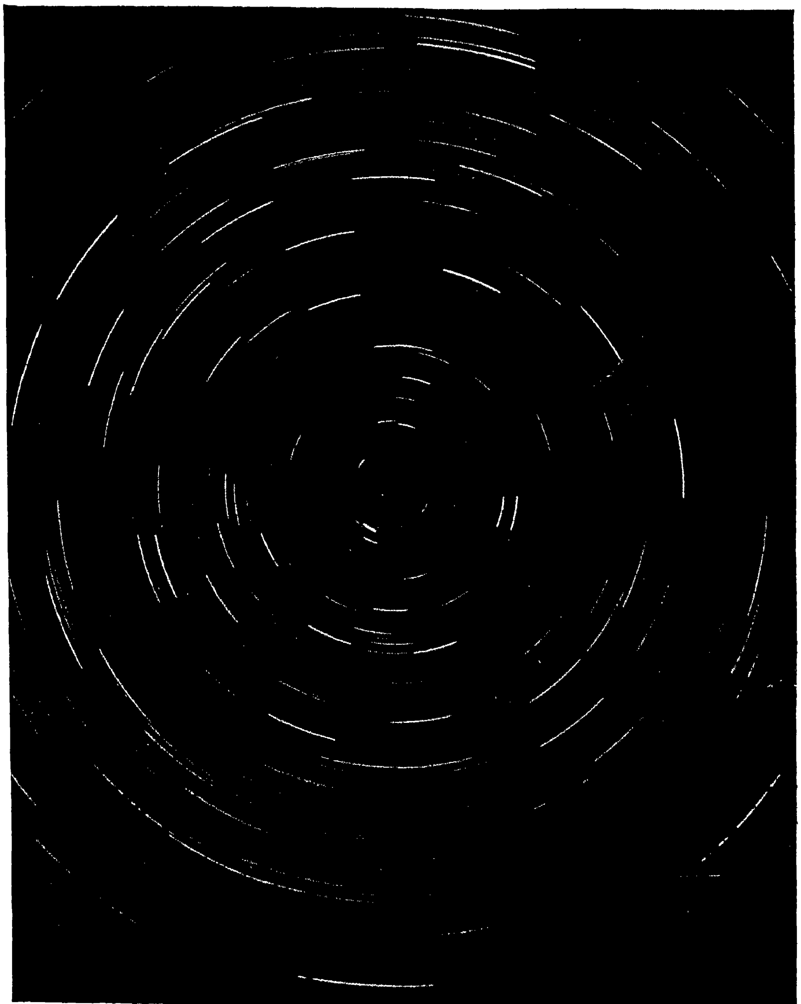
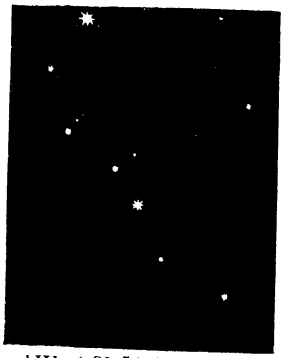


Photo by] [*The Yerkes Observatory*

POLAR STAR TRAILS

This photograph was the result of pointing an ordinary field camera towards the northern sky and leaving it in the same position for about an hour During the exposure the Earth, carrying the camera with it, has been rotating, and this has caused the stars to trail on the plate The short, bright trail near the centre was made by the Pole Star itself, which is very near, but not exactly, at the North Celestial Pole, the point to which the Earth's axis is directed

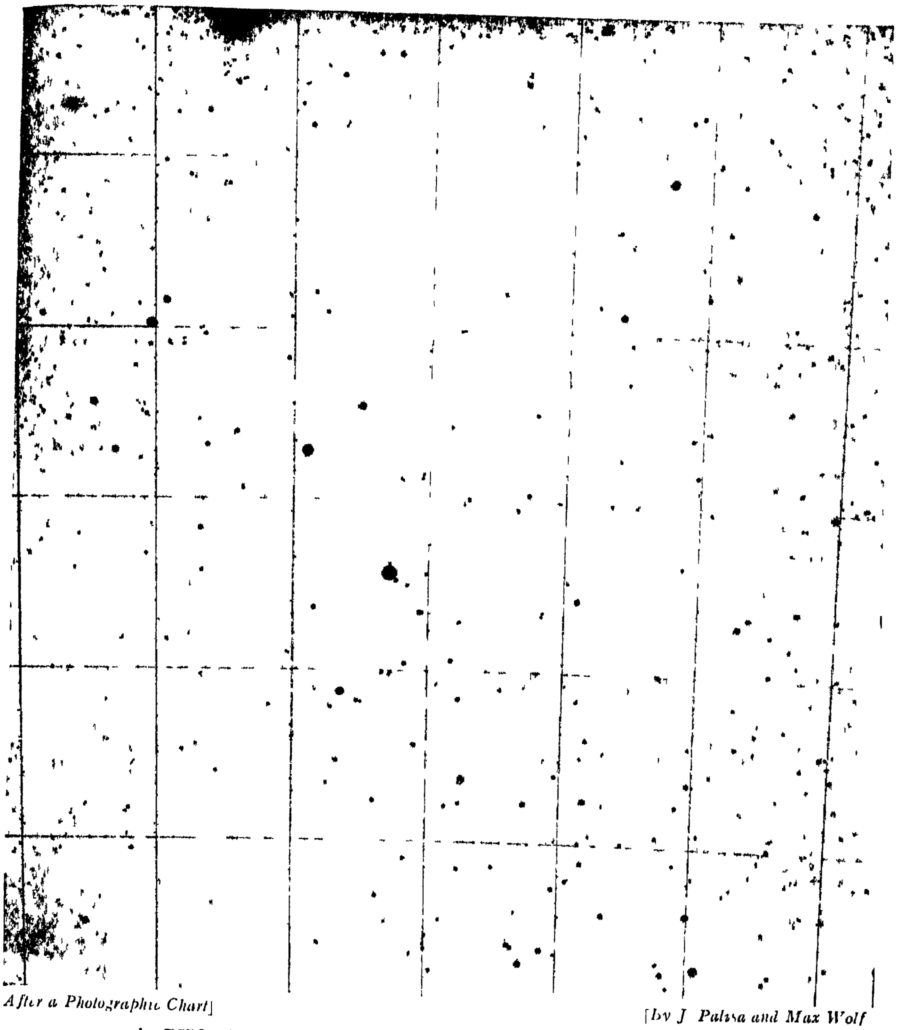


THE CONSTELLATION PERSEUS SEEN WITH THE NAKED EYE

Very few stars are visible, and prolonged gazing will not increase the number.

Our modern observatories are equipped with both refracting and reflecting telescopes. Each possesses special advantages which make it suitable for particular kinds of work. The chief merit of the reflector is that it can be made in very large sizes, principally because glass of only one kind is used, and its transparency and general quality are not of very great importance. The images yielded by the reflector are entirely free from false colour, and this makes the type particularly useful for photographic work. On the other hand, reflectors are apt to be affected in their performance by changes of temperature, and their open tubes encourage the formation of air-currents, which are harmful to critical definition. These drawbacks do not apply in the same degree to refracting telescopes. We may sum up by saying that, in general, reflectors are used where the maximum collection of *light* is desired, while refractors are preferred for the examination of minute *details* with high powers, where a steady image is essential.

An astronomical telescope is really a more simple instrument than the common pocket spy-glass. If we take one of the latter to pieces we shall find no less than four glasses between the eye and the large lens. The astronomer is content with two, or sometimes only one. By this more light is gained, but objects are always seen upside down. A question nearly always asked by visitors to an observatory is "How much do these large telescopes magnify?" No simple answer can be given, for the magnifying power depends upon the eye-piece, and the astronomer can obtain almost any



After a Photographic Chart] [*by J. Palisa and Max Wolf*

A PHOTOGRAPH OF THE CONSTELLATION PERSEUS

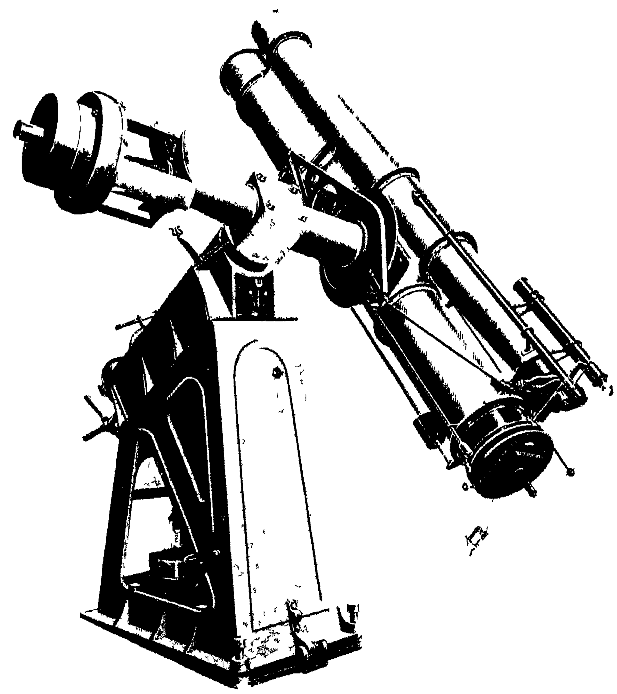
The same stars shown in the small sketch will be recognised, with the addition of thousands of fainter stars, all simultaneously recorded in their correct places. The plate was exposed for about an hour, and many more stars would be recorded by a longer exposure. The relative brightness of the stars can readily be deduced by measuring the diameters of their images on the plate.

THE GREAT COMET OF 1882
This was the first really successful photograph of a comet ever obtained The large number of stars present on it suggested to Sir David Gill (who took the photograph) that the mapping of the Heavens could be rapidly and accurately carried out by means of the photographic plate

power he likes by simple substitution of this trifling piece of apparatus But for every telescope there will always be a maximum power that can *usefully* be employed, and this will depend on the size of the object-glass or large mirror Only a certain amount of light is available, and we shall get a very dim picture if we spread it out too much Moreover, the air through which we are looking is nearly always in a state of more or less agitation, and the distortion thus produced in the image will only be increased if we magnify it to excess In brief, it may be said that, while powers between 1,000 and 3,000 are very occasionally used on the largest telescopes, lenses are most generally chosen which will enlarge the apparent diameter of an object from 100 to 700 times, the actual power selected will depend on the size of the telescope, the condition of the atmosphere, and the nature of the object examined For comparison, it will be recalled that an ordinary prism-binocular magnifies about eight diameters Large telescopes are, with certain exceptions, so mounted that they can be directed to any part of the heavens, and a clockwork mechanism keeps them pointed continuously on any desired object in spite of the rotation of the earth

* * * *

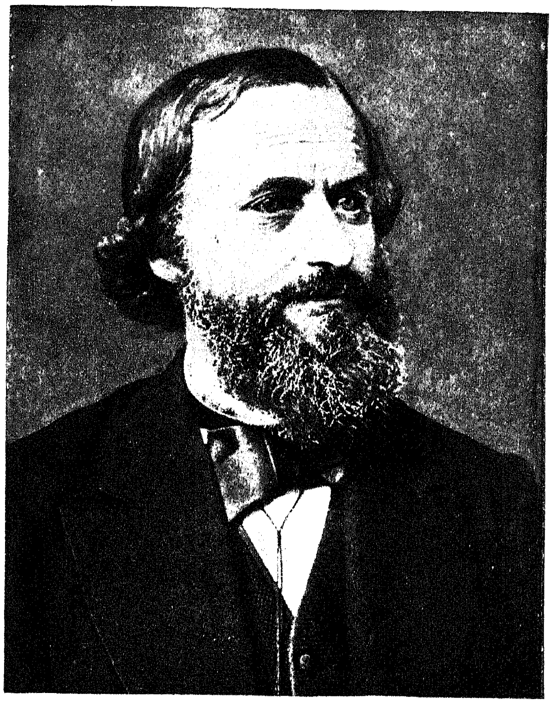
We have spoken of the telescope as being in reality a gigantic eye, but, strictly speaking, it is only half an eye Human vision is not merely the formation of a picture by a lens, for such a picture is only of use when it has the sensitive surface of the retina to fall upon All that the telescope, as described so far, accomplishes, is to provide our eye with a much bigger lens It does not give us a more sensitive retina, and in observing we use the one we have already But there is a way in which we can complete the resemblance of the telescope to the eye, for the science of the Nineteenth Century has given us in the photographic plate a new and artificial retina of great



THE STANDARD "ASTROGRAPHIC" TELESCOPE
By means of an instrument of this kind the Heavens can be mapped photographically in small sections with great accuracy The type shown was that adopted in 1887 for use in 18 observatories, scattered throughout the world The great photographic atlas that was to result from this is still incomplete

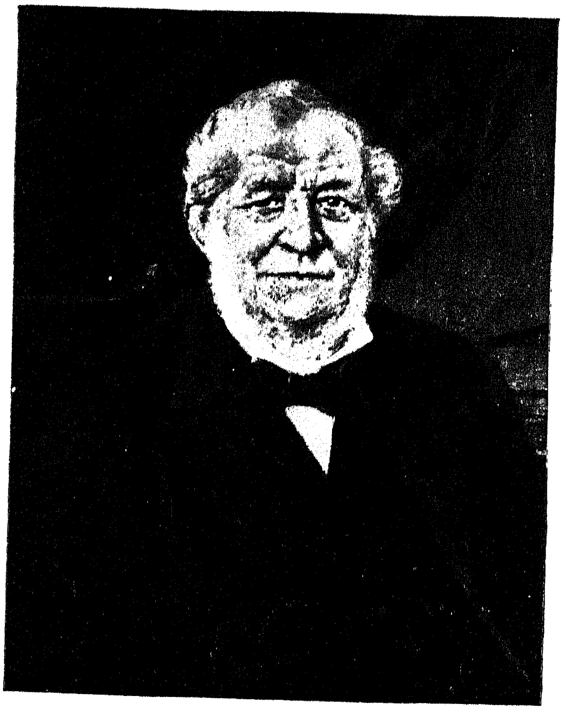
FRAUNHOFER.

Aided by improvements in the manufacture of optical glass, Fraunhofer greatly developed the refracting telescope early in the Nineteenth Century. He was the first man to map the dark lines in the Solar Spectrum, and his name is still associated with them.



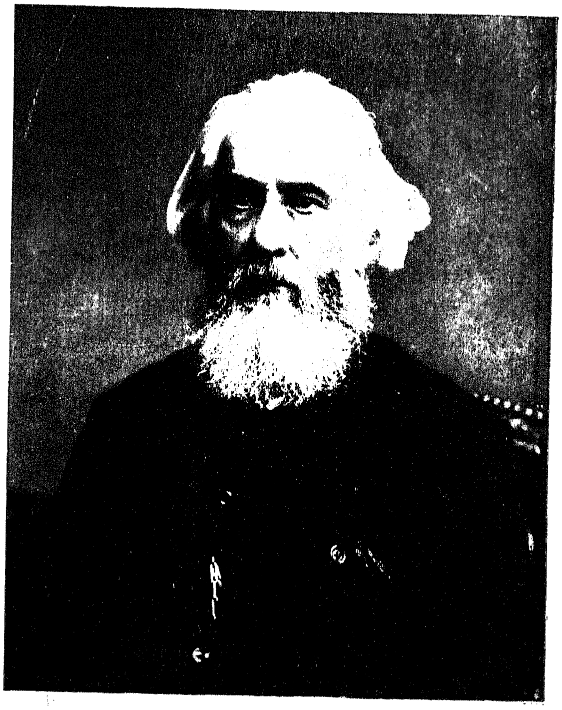
KIRCHHOFF.

Kirchhoff investigated the problem presented by the "Fraunhofer lines" in the Solar Spectrum, and was the first to explain them as being due to the gases of well-known elements, present in the Sun's atmosphere.



BUNSEN.

Bunsen was associated with Kirchhoff in investigations connected with spectrum analysis. He invented a type of gas-burner which, producing a hot flame of low luminosity, facilitated the vaporisation of various substances and the study of their spectra.



HUGGINS.

Sir William Huggins was the first man to make a detailed study of the spectra of the stars, and modern stellar spectroscopy is a development of his pioneer work. He was the first to prove that certain nebulæ are truly gaseous.

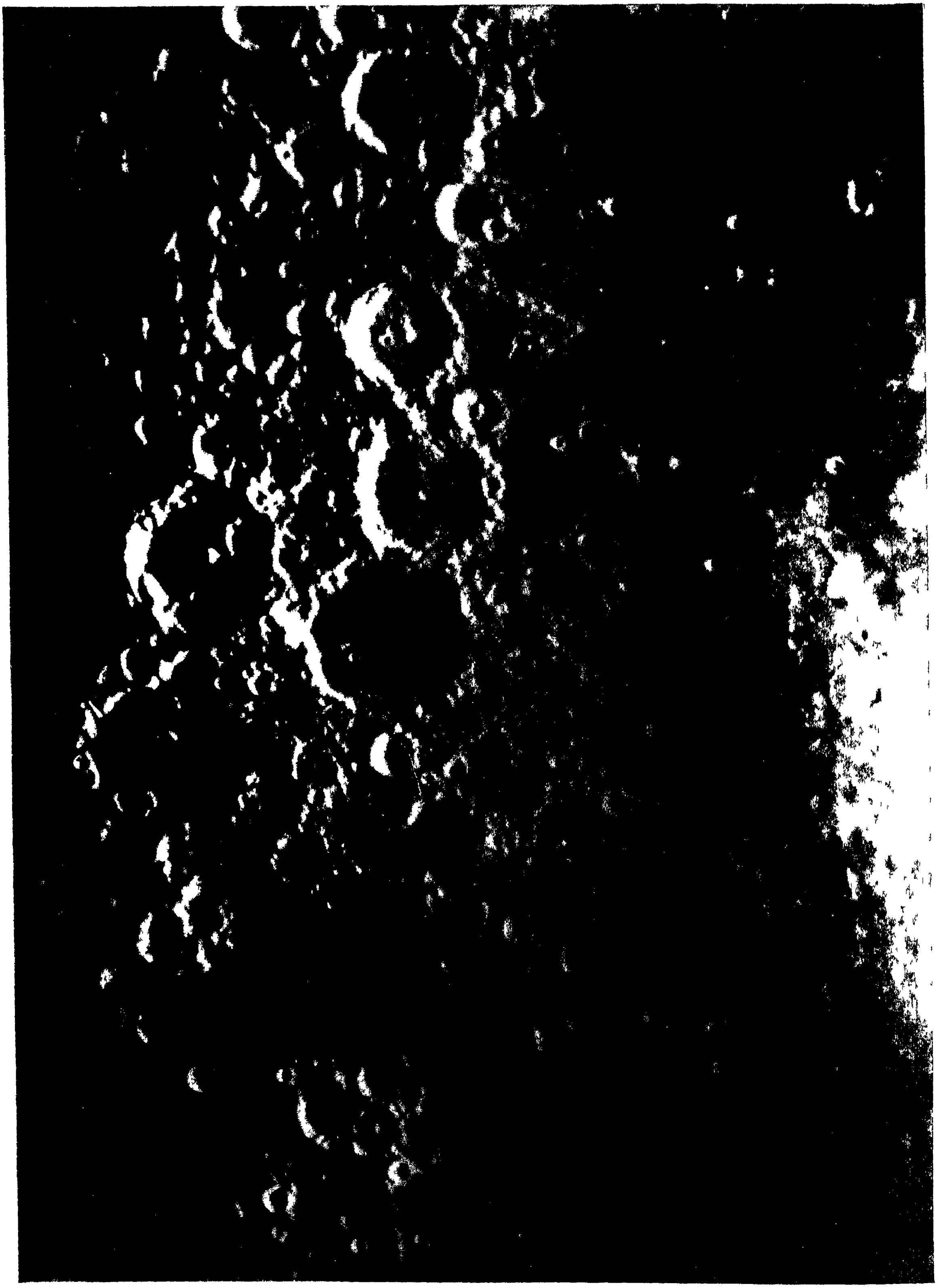
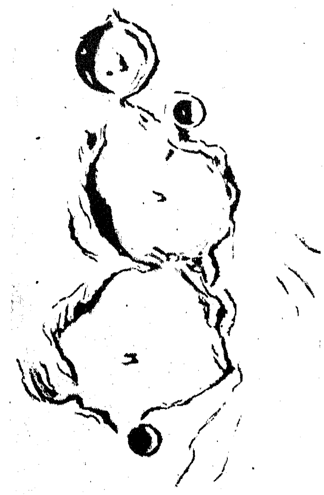


Photo by] [*The Lick Observatory*

A PHOTOGRAPH OF THE REGION OF THE LUNAR CRATER "PTOLEMY"

Photography of the Moon's surface is chiefly of use in fixing the outlines and relative positions of the various features Photographs such as the one above serve to give a very good general idea of lunar landscapes, but, though taken with large telescopes,



DRAWING OF "PTOLEMY" AND ITS NEIGHBOURS.

This sketch represents an attempt to delineate at the telescope the general outlines of the craters seen in the centre of the preceding photograph. The result is far from accurate, and much valuable time is wasted, which would have been better employed in filling in the details absent from the photograph. The latter was secured in a single second of time.

sensitiveness. We have only to combine this artificial retina with a lens which will throw a picture upon it, and we at once have a real model of the eye on a large scale. Such a combination is, of course, familiar to us all as the photographic camera.

The cameras to which most of us are accustomed are small affairs, generally from a few inches to a couple of feet in length, but we should bear in mind that the combination of a plate with a lens of *any* size or focal length still constitutes a camera. Thus, if we remove the eye-piece of a giant telescope and substitute a photographic plate, we at once produce an instrument which is just as much a true camera as is our little pocket kodak.

The possibility of using photography as a means of portraying celestial objects occurred very early to the pioneer workers. In fact, some of these pioneers, including Sir John Herschel, were themselves astronomers of distinction. The great bar to progress in these early days was the lack of sensitiveness of the old "wet" plate. In consequence of this, only the brightest objects, such as the Sun and Moon, could be properly photographed. Moreover, the pictures produced by the new method showed much less detail than could be seen by the eye at the telescope; and so for many years celestial photography was regarded as little more than a scientific curiosity, of very small practical value to the astronomer. But the whole aspect of affairs was changed by the advent of the dry plate, which was not only much more sensitive than its wet predecessor, but was far more easy to handle. The result of this new improvement was a revival of interest in celestial photography; for it was now possible to extend the grasp of the camera to include the feeble light of the fainter stars, which had hitherto been out of reach. The importance of this may not be apparent to the reader at first sight, and even the astronomers themselves were, for the most part, slow to realise it. Probably the first man to appreciate its full significance was Sir David Gill, then Her Majesty's Astronomer at the Cape. In the year 1882 he secured some very beautiful photographs of the great comet which was then visible. On developing the photographs (which were taken with an ordinary camera), Gill was struck, not merely by the successful portrayal of the comet, but also by the large number of faint stars which had been recorded along with it, and he at once realised the important fact that, in photographing the comet, he had simultaneously secured an excellent *chart* of a large portion of the Heavens.

From "Astronomy for All."] [*By permission of Messrs. Cassell & Co., Ltd.*

EXAMINING AND MEASURING A CELESTIAL PHOTOGRAPH.

Once a photograph of the sky has been taken, it remains as a permanent record, and can be at any time submitted to minute examination and measurement. Special machines are designed for this purpose and, at Harvard and elsewhere, much of the work is done by women.

Photo by] [*The Yerkes Observatory*

THE BRUCE PHOTOGRAPHIC TELESCOPE OF THE YERKES OBSERVATORY

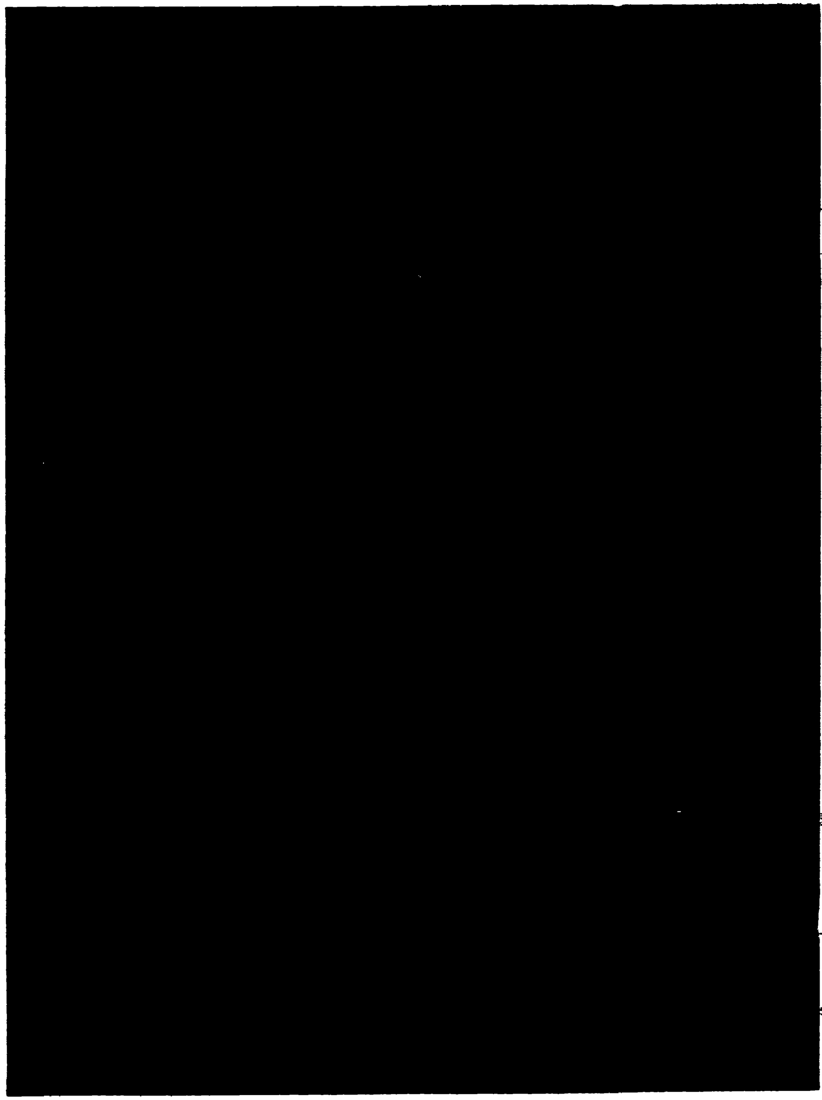
This instrument was specially designed for the photography of the Milky Way, and magnificent pictures of the latter were obtained with it by the late Professor Barnard

Now, the accurate mapping of the stars in the sky has always been, and still is, of fundamental importance to astronomers, for it enables them to fix exactly the positions of the wandering planets, and also to detect changes and movements among the stars themselves But the making of a good star-chart is not a simple matter The position of each star has to be measured separately, which takes a very long time if the chart is to include many faint stars and even when the work is over, there are bound to be errors of measurement and recording which are difficult to check It will be readily seen that the case is very different when a chart is made by means of photography, for the process is now *automatic* A thousand stars may simultaneously record themselves upon one plate in the course of a few minutes, which means a great saving of time The personal element, too, is thus eliminated, and we may be sure that each star is in its right place This much Gill realised, but he also saw that his pictures were on so small a scale that the positions of the stars recorded on them could not be measured with the exactness required by astronomers Indeed, it seemed rather doubtful whether such minute accuracy could ever be secured by photographic means, even with much larger instruments But meanwhile this very matter was being investigated by the brothers Henry at the Paris Observatory After various preliminary experiments they constructed a special lens 13 inches in diameter, and fitted it to a camera over 11 feet long This gave a much larger scale to the photographs than the small cameras hitherto used, and it was found that the positions of stars could be measured on the plates with an accuracy comparable to that attainable by the old visual methods The

From "Knowledge," by permission of] [*The Astronomer Royal*

THE THOMPSON TELESCOPE, ROYAL OBSERVATORY, GREENWICH

This gigantic camera, 26 inches in aperture, and 22½ feet long, is chiefly employed for the determination of stellar distances The plates taken with it are on a large scale, and can be measured with very great accuracy A visual telescope, of smaller size, is mounted alongside of the large camera to facilitate accurate guiding of the instrument during the time of exposure



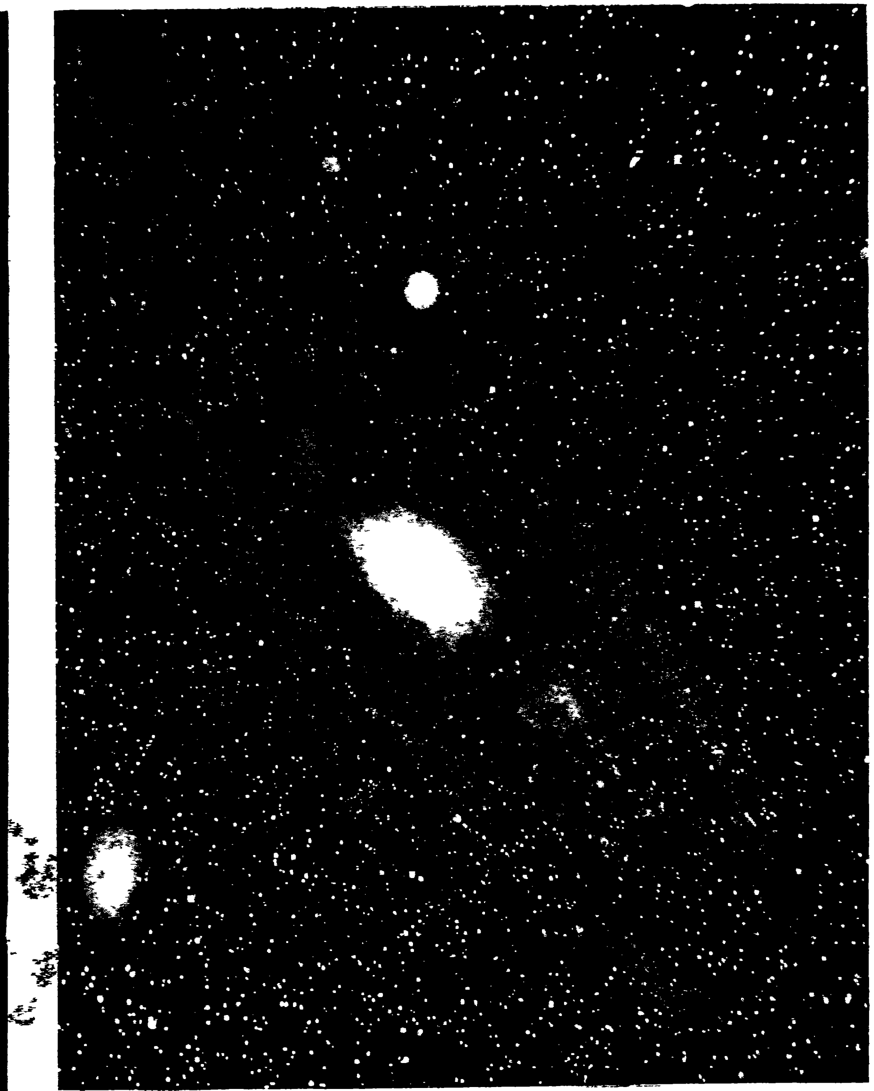
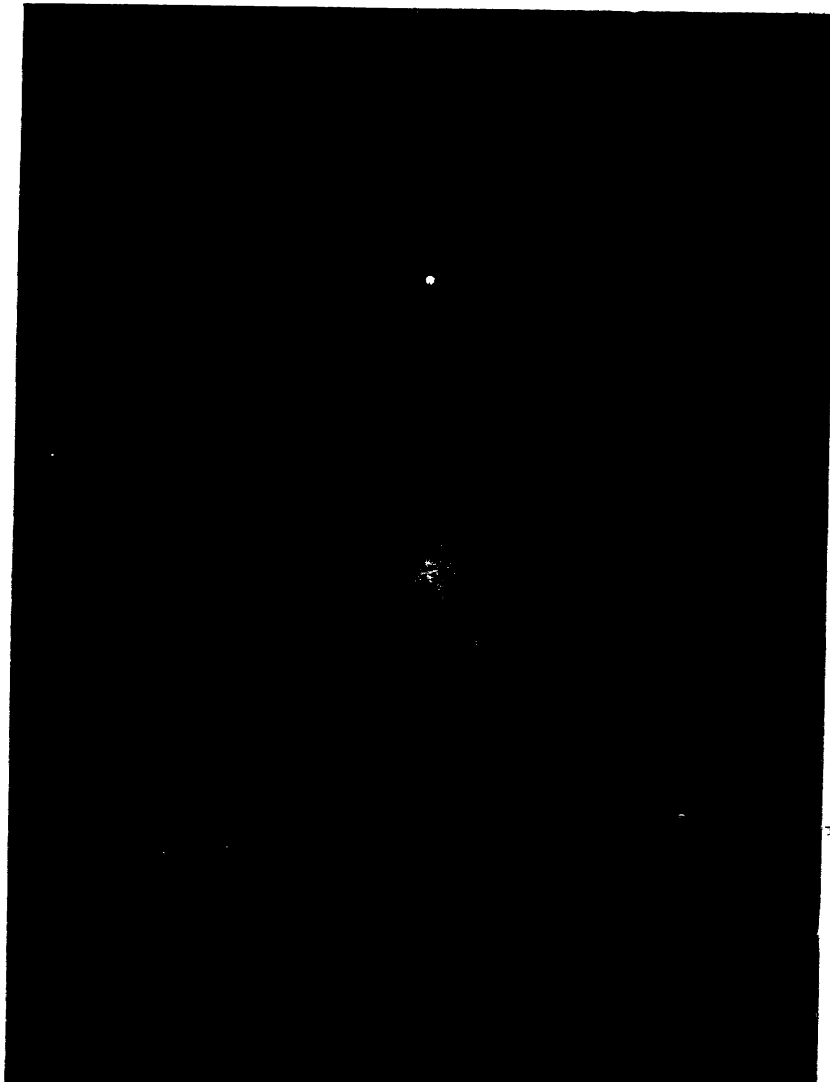


Photo by] [*The Yerkes Observatory*

AN OLD DRAWING AND A MODERN PHOTOGRAPH COMPARED

It is hard to realise that both these pictures represent one and the same object, the Great Nebula in Andromeda. The drawing was made with quite a large telescope and shows nearly all that can be made out by visual means alone And yet it gives no idea of the true spiral structure of the object This is partly because only a small portion of the whole is visible at one time through a powerful telescope whereas the complete extent of the Nebula is included on the photograph, which also shows faint portions that are quite invisible to the eye



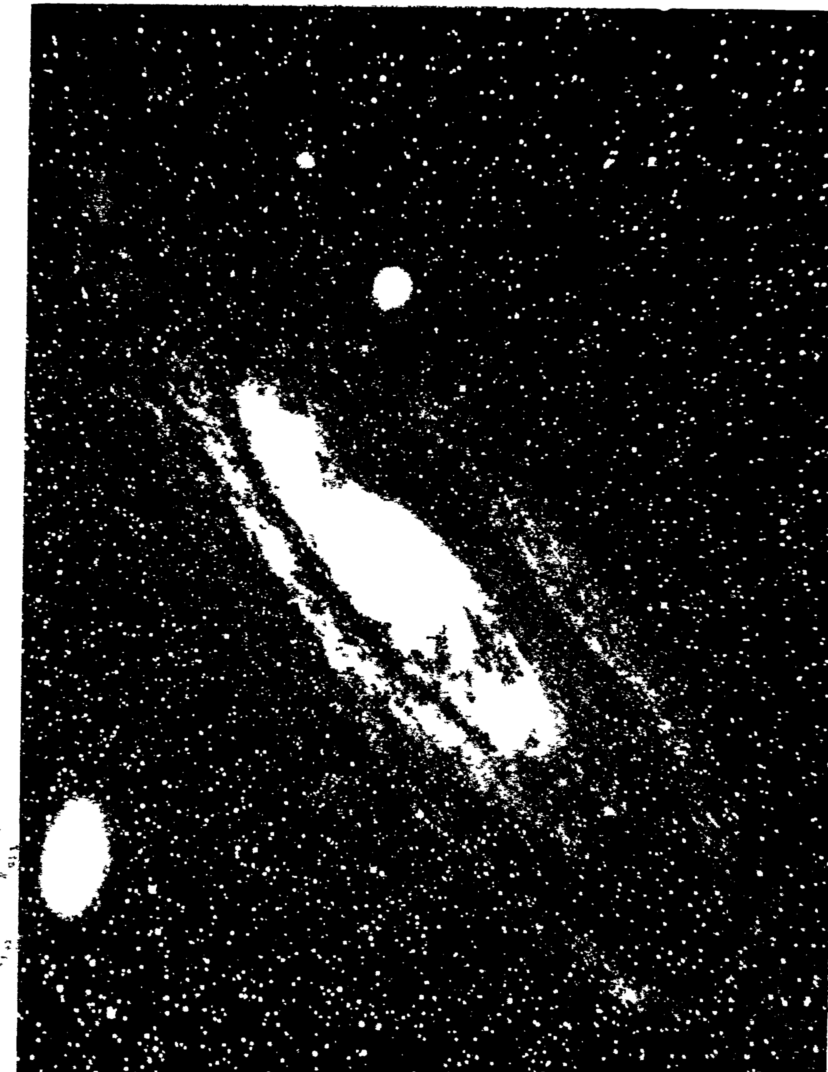


Photo by] [The Yerkes Observatory

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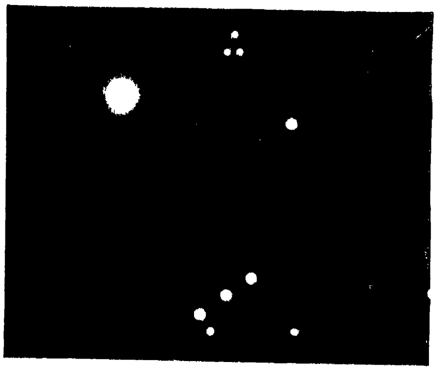
From "Knowledge," by permission of] [*The Yerkes Observatory*

NEBULOSITY IN THE PLEIADES

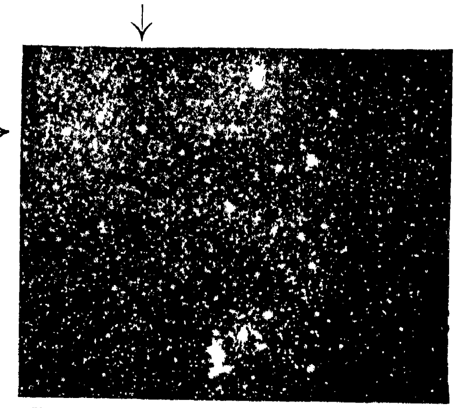
The stars forming this well known cluster are involved in nebulosity of a tenuous wispy character Some of this is just faintly visible in a large telescope, but most of it is beyond the reach of the eye, partly because of the dazzling effect of the bright stars The photographic plate is not affected in this way except very near to the images of the stars, and a perfect picture of the faint nebulosity is obtainable with a sufficiently long exposure



NORTHERN PORTION OF ORION

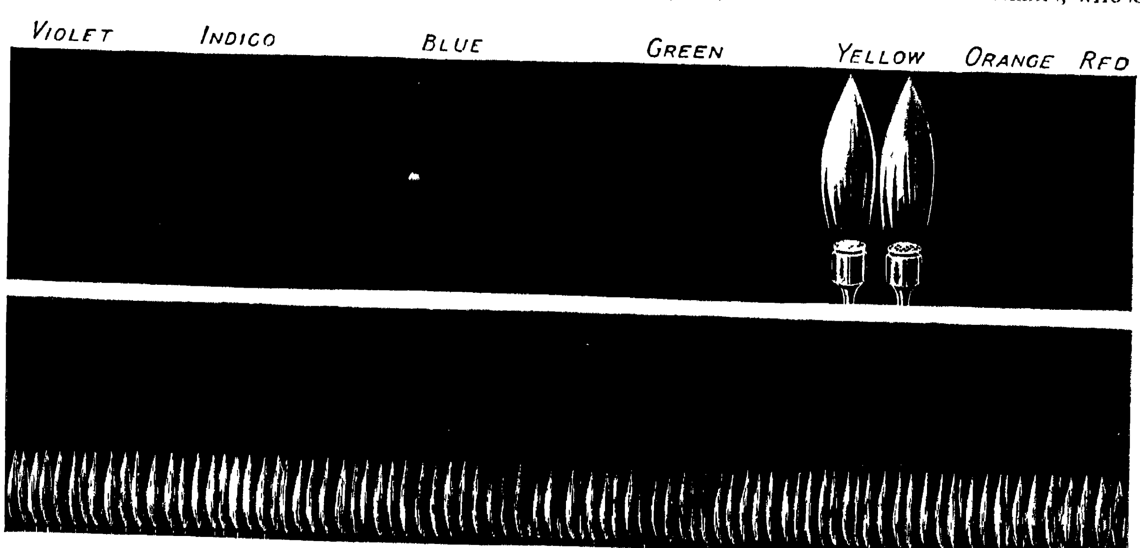
This is the view obtained by the eye. The prominence of the great star Betelgeuse, in the "Giant's Shoulder" will be noted.

only drawback was that, with such a large scale, only a very small portion of the sky could be photographed at one time. In fact, it would require ten thousand plates to cover the entire sky, and the labour of taking even half of these and of measuring the millions of star-images upon them would be far too big a task for one observatory to accomplish. Accordingly, the co-operation of other astronomers was invited, and, at a conference held in Paris in 1887, it was arranged that 18 separate observatories should join in a systematic scheme for photographing the entire sky, each using an instrument similar to that of the Henry brothers. To this day, unhappily, the scheme remains unfinished, but what has been done has amply demonstrated the soundness of the methods employed, and much information of great value has already been derived from the plates taken. The great merit of such a chart is its extreme accuracy, due to the length of the camera employed. But, for some of his purposes, the astronomer needs merely a *picture* of a portion of the sky and is not concerned with the exact positions of the stars on it. He then makes use of a different kind of photograph, taken with a comparatively small camera, whose length may be anything from a few inches to about four feet. With such an instrument large portions of the sky can be photographed at the same time on one plate, the scale being so small. In fact the whole sky can be charted on quite a small number of plates by one man in a reasonable time. This was actually done some years ago by the late Mr. Franklin Adams, whose



PHOTOGRAPH OF NORTHERN PORTION OF ORION

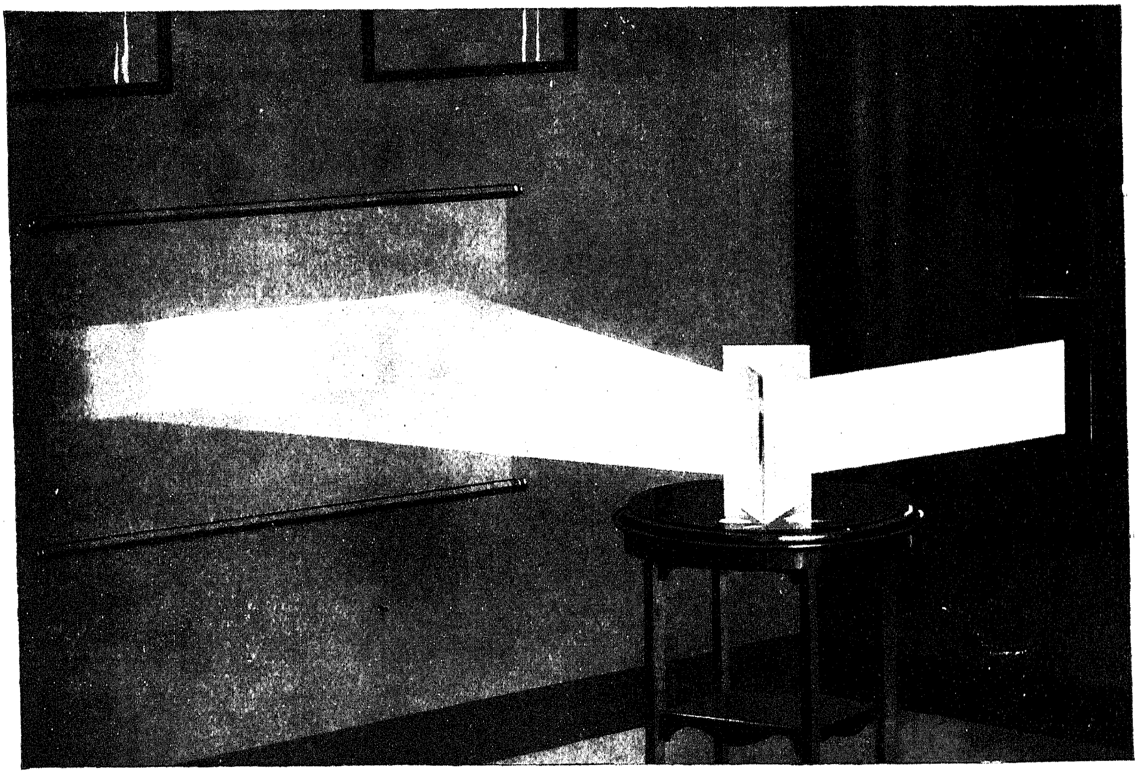
This shows how feebly a red star affects the photographic plate. Betelgeuse appears here as a comparatively faint star, owing to its redness.



EMISSION SPECTRA

A glowing gas owes its light to rays of comparatively few colours, whereas incandescent solids (as the carbon particles in a candle flame) give out light of all colours. A prism applied to either type of light will produce what is known as an "emission" spectrum, but in the case of the candle flame the number of colours present is almost infinite, so that the images overlap. Such a spectrum is said to be "continuous."

206 charts, covering the entire sky, have proved of great value to astronomers. At the Harvard College Observatory, in America, a camera only about a foot long is in use on every fine night, and by its means every part of the sky visible from that latitude is photographed several times each year. This method of repetition is of great value for the detection of changes in the light of the stars, and many " new " or temporary stars have been brought to light in this way. Photography is now very largely used for determining the relative brightness of the stars. Great accuracy is attainable by this method, but the results are not directly comparable with those obtained by the eye. The differences are due to the colours of the stars, which affect the plate and the eye in an unequal manner. Thus, for instance, red stars are much fainter on a photograph than they appear visually. The difficulty is now being overcome, but at the expense of a good deal of extra labour in elaborating the methods used.



HOW A "PURE" SPECTRUM IS FORMED.

To prevent overlapping of the coloured images seen through a prism the light is made to pass through a narrow slit. The colours are then seen more nearly separate, and the spectrum produced is said to be pure. The degree of "purity" increases as the slit is made more narrow.

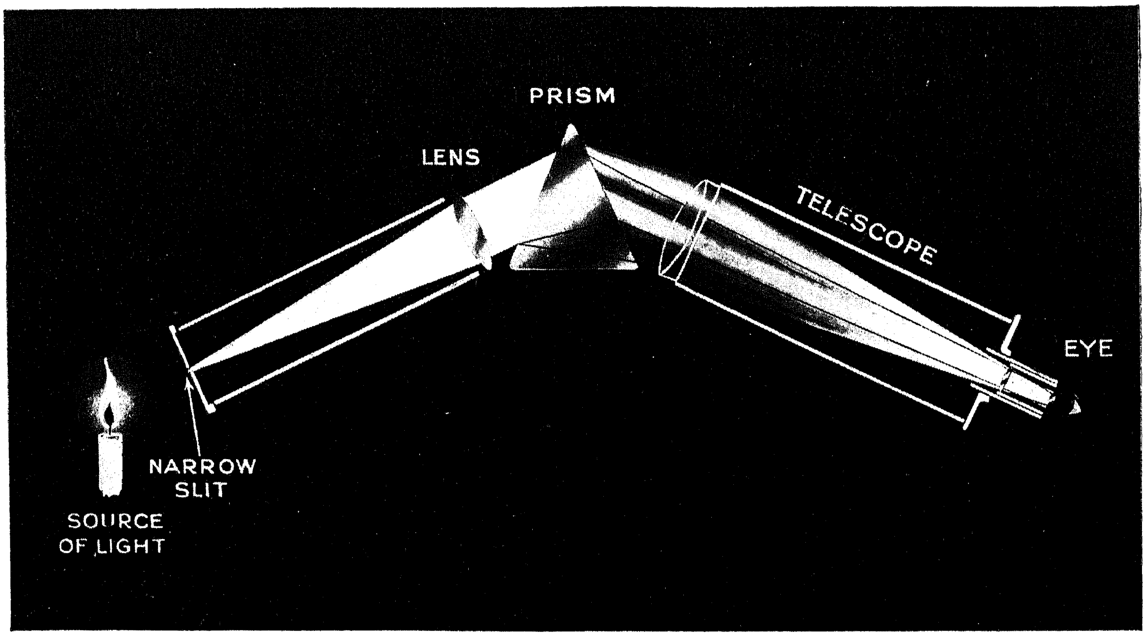
Photography has of late years been very successfully applied to the portrayal of the surfaces of the Sun, Moon, and planets, but it has not been found possible to photograph with any telescope details that are too minute to be seen with much smaller instruments. The value of the photographs consists rather in the rapidity with which the records are obtained, and in the *general accuracy* of the pictures. Thus, in the case of the Moon, a good photograph will serve to fix once and for all the relative positions of the various features and their general outline. It is left for the visual observer to fill in the details that are too small to be photographed.

Thus far celestial photography has been considered rather in its aspect of a labour-saving device for the astronomer, who could, by expending much time and trouble, do most of the work nearly as well by visual means. But the sensitive plate has certain properties which render it definitely superior to the eye in some other departments of astronomical work. Our eyes can only perceive light that is of a certain intensity, and objects fainter than this are invisible to us. Prolonged gazing

By permission of] [*E N A*

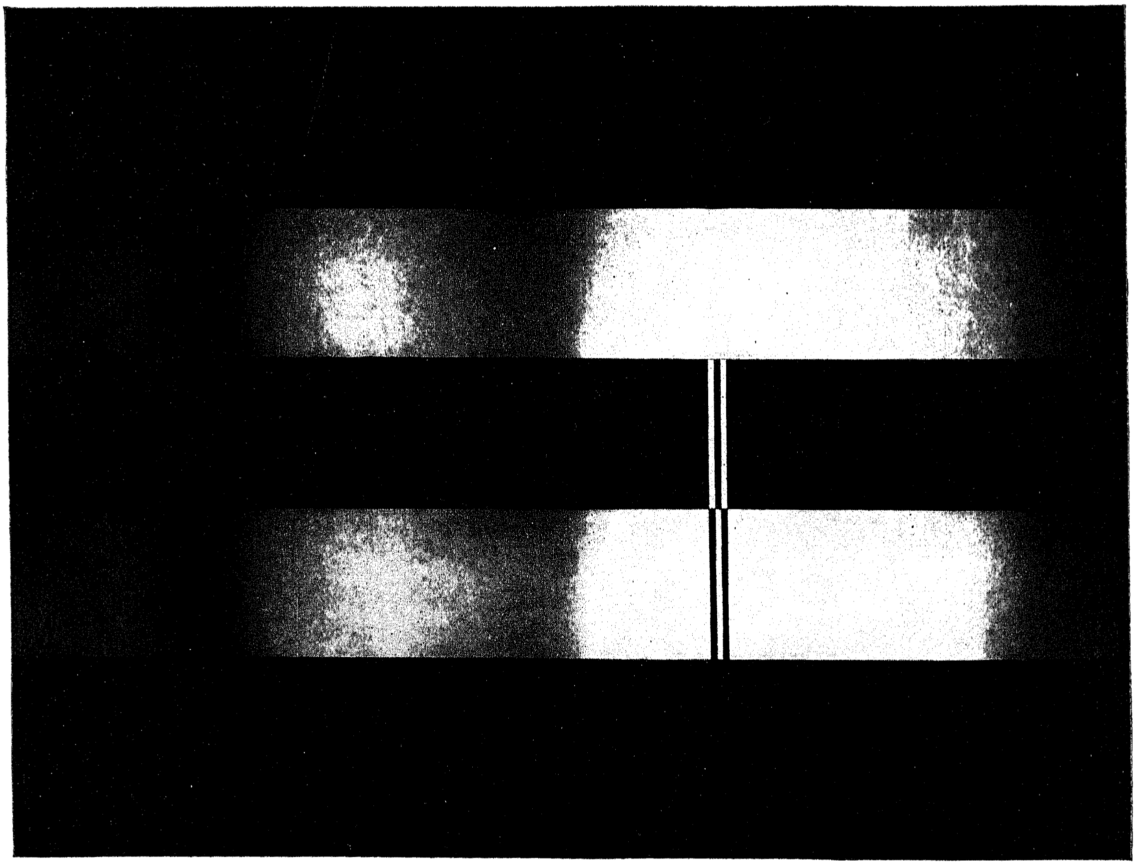
THE SUN'S ATMOSPHERE OF HYDROGEN

Such a photograph as this would have been quite impossible to obtain without the aid of the Spectroheliograph, whose action is described and illustrated on another page The layer of Hydrogen flames which covers the whole Sun is quite transparent, and is far too faint to be seen against the glare of the solar surface. By means of the Spectroheliograph the faint light given out by the Hydrogen



PRINCIPLE OF THE SPECTROSCOPE.

The rays which pass through the narrow slit are made parallel by means of a lens. They then pass through a prism which disperses them into a spectrum. The latter can be examined with a small telescope (as shown in the illustration) or focussed upon a plate by a photographic lens.



THE THREE GREAT TYPES OF SPECTRUM.

An incandescent solid gives out light of all colours and yields a "continuous" spectrum. A glowing gas gives a spectrum of a few bright lines of certain definite colours. But the same gases, when shining in front of a hotter body that is giving a continuous spectrum, have their bright lines "reversed," or made dark, and are then said to produce an "absorption" spectrum.

makes matters worse rather than better, since the eye, like the rest of the body, is subject to fatigue. The case of the photographic plate is different, for it continues to pile up its impressions all the time that it is exposed. A star that is too faint to be recorded in a few seconds of time will continue to bombard one small spot on the plate with its feeble light until the sensitive film at last begins to be affected. And the process will not stop here, for the plate never gets tired, and will continue almost indefinitely to respond to the bombardment until an image of great intensity is produced. It follows, then, that very faint objects, such as most of the nebulæ, are better studied by photography than by the eye. All that is required is a large telescope, preferably a reflector, and an exposure whose length, varying with the brightness of the nebula, may be anything from a few seconds to several hours. In this way have been secured wonderful pictures which have entirely revolutionised our knowledge of bodies of this kind. Some of this increase of knowledge could have been secured by

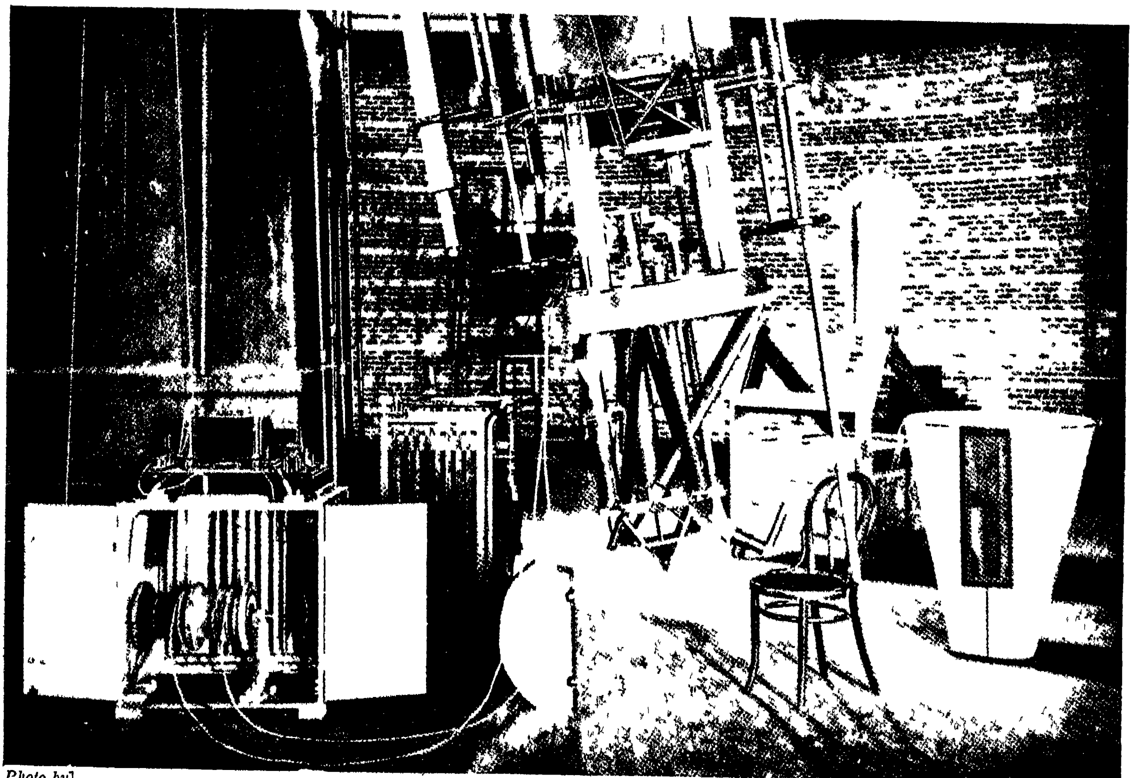


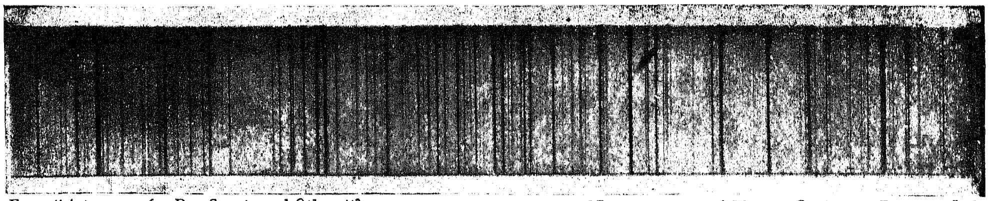
Photo by] [*The Yerkes Observatory*

THE BRUCE SPECTROGRAPH, YERKES OBSERVATORY

This picture shows how a photographic spectroscope can be attached to a large telescope in place of the usual eye-piece. The positions of the prisms are clearly shown by their triangular metal mountings. The U shape of the whole instrument is necessitated by the bending of the Light as it is dispersed by the prisms, and the rays finally forming the spectrum are opposite in direction to the original beam.

greatly increasing the size of visual telescopes (if this were possible), but certainly not all of it, for many of the rays which affect a plate are beyond the range of human vision, however bright they may be. A mere increase of the size of the telescope can never make them visible.

Any ordinary camera can be used to secure photographs of the stars, or at any rate of the brighter ones. It is only necessary to focus the camera for distant objects, insert a plate or film, and point the apparatus to the sky. But, with an exposure long enough to be of much use (say five minutes), the result will be a series of lines where the small star-points should be. This is an effect of the rotation of the Earth, which has moved the camera bodily, leaving the stars behind. So the astronomer, to obtain a clear picture, must always keep his camera in steady motion so as to point continuously at the stars being photographed. This is done by mounting the camera alongside of a telescope driven



From "Astronomy for Boy Scouts and Others."] [*By permission of Messrs. C. Arthur Pearson, Ltd.*

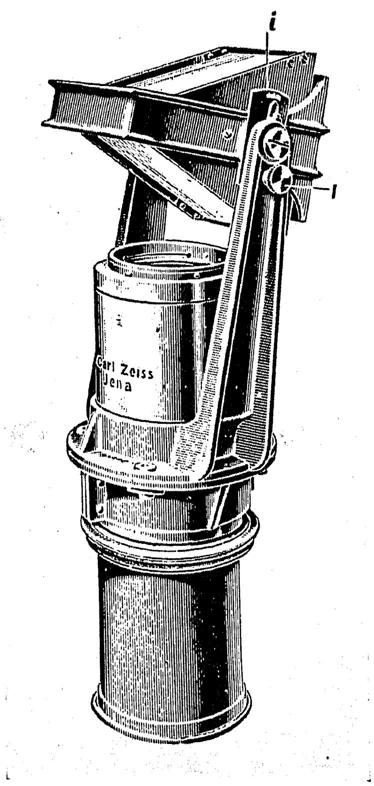
THE SOLAR SPECTRUM.

The background of the Sun's spectrum is continuous in the main, but it is crossed by numerous dark lines, due to absorption of certain rays by the gases of the solar atmosphere. These gases can be identified by comparing the positions of the lines with those furnished by the same elements in our laboratories.

by clockwork, and during the whole exposure the operator must, by inspection through the telescope, see that the apparatus is being properly driven by the mechanism. If things are not going smoothly the movement of the clock can be altered, or the plate itself slightly shifted.

* * * * * * * * * * * *

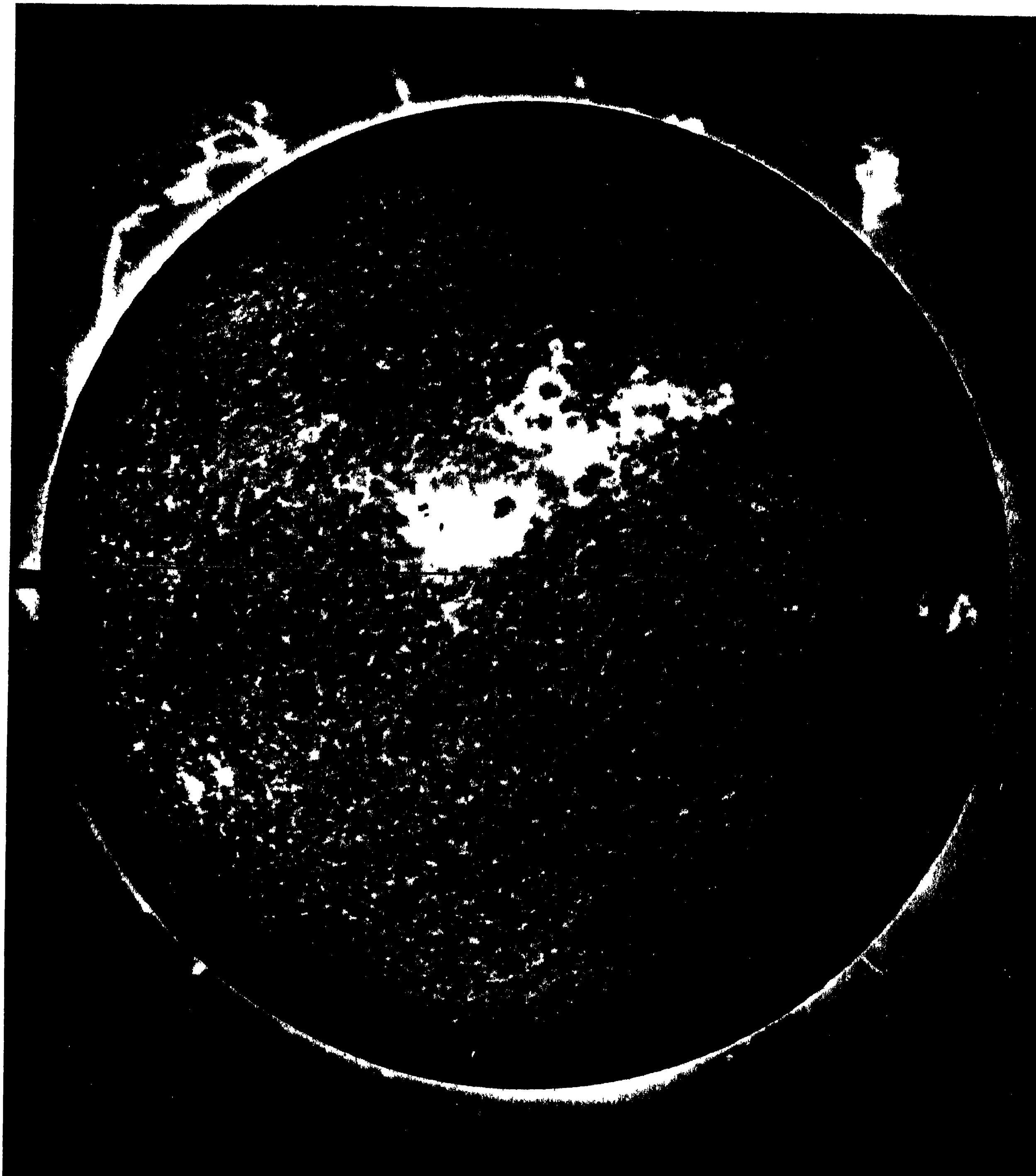
The amount we can learn about the heavens by the use of the telescope and camera is truly astonishing, for these instruments, helped by mathematics, have revealed to us the position, distance, shape, size, weight, colour and brightness of bodies that are millions of miles away from us. But they leave one all-important question unanswered. No amount of mere gazing at a star can tell us with certainty what it is *made of*; and the astronomer of a hundred years ago, armed with telescope alone, had to say, like the child in the rhyme: "How I wonder *what* you are!" He could, it is true, make shrewd guesses from the very appearance of certain objects, but, as he could not actually handle them, he was never quite sure how far these appearances were deceptive. But in the first half of the Nineteenth Century, a discovery was made which eventually supplied him with the answer to his question. The essence of this discovery was that there exists a connection between the chemical (and physical) nature of a substance and the character of the light which it emits. The importance of this to the astronomer will be clear enough, for now was opened up to him a means of studying the nature of distant bodies whose one connecting link with him was their light.



AN OBJECTIVE PRISM.

By mounting a large prism in front of the "objective," or large lens, of a telescope, the spectra of many stars can be photographed simultaneously. No slit is required owing to the smallness of the stars' images.

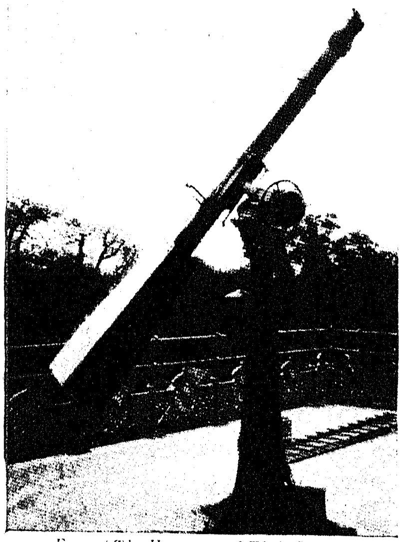
We have already seen how a prism bends light of each colour by a different amount, so that, by looking at a light through a prism, we can see just how many colours are really present in it. If we examine any white-hot *solid* substance—such as steel, lime, or carbon—with a prism, we shall see that its light contains all the colours of the rainbow, spread out into a ribbon called a spectrum. But this is not the case with a glowing *gas*. If we throw some salt into a spirit-flame we shall produce a yellow light, which is really the glowing vapour, or gas, of Sodium. Looking at this flame through a prism we shall find that, instead of a rainbow-band of colours, a single yellow flame is seen, as by direct view without the glass. This simply means that Sodium gas gives light of one colour only. Other gases, such as Hydrogen, give out, when heated, Light rays of several colours, so that we shall see through the prism numerous flames, each of a different tint. Each flame will appear in a different place, since the prism bends the colours unequally; and there will be large dark spaces between them, showing



After Hale]   [*From "Knowledge*

CALCIUM CLOUDS ON THE SUN

Beneath the Sun's layer of Hydrogen (shown in an earlier illustration) and nearer to his bright surface, are found vast cloud like masses of Calcium, reduced, like all other elements, to the gaseous condition by the fierce heat These Calcium clouds are, like the Hydrogen layer, quite invisible to direct observation, and for the same reason In order to secure this photograph all rays were excluded by the Spectroheliograph, save those given out by the glowing Calcium vapour



From "The Heavens and Their Story." By courtesy of the Epworth Press.

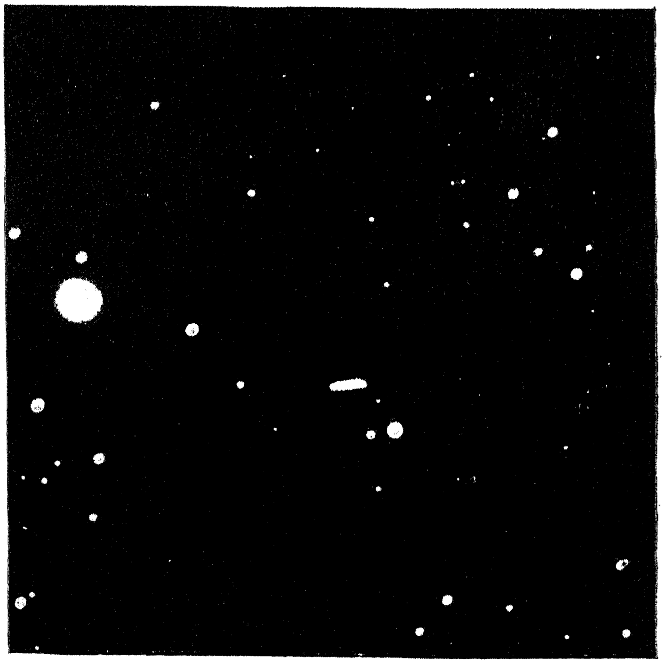
THE GREENWICH PHOTOHELIOGRAPH.
This small telescope is used daily at the Royal Observatory for securing photographs of the Sun and his spots. Each picture is carefully measured and a complete record is kept of the general appearance of the solar surface.

what colours are *missing* from the light. Now, the light of a candle comes from minute particles of glowing carbon, and when looked at through a prism, appears to contain rays of every colour. In fact, we see innumerable flames of every shade spread out in a continuous strip. But these coloured flames, being large, overlap one another to such an extent that we cannot, by this rough method, be quite sure that no colours are missing. We cannot make the flame small enough to prevent this overlapping, but by putting a narrow slit between flame and prism we can cut the former down to a fine line of light.

The spectrum now produced, nearly free from the overlapping effect, is called a "pure" spectrum; but we shall find that, though the colours are more clearly defined than before, there are still no gaps in it, and it is said to be "continuous." But, if now we hold up our slit towards a sun-lit cloud, and examine its spectrum through the prism, we shall see a number of narrow dark spaces, or lines, each the shape and width of the slit. This shows us that the spectrum of the Sun is not perfectly continuous: certain colours, corresponding to the dark spaces, are missing. An observation of this kind was first made by Wollaston, in 1802; and, in 1814, Fraunhofer, using a very narrow slit and magnifying the spectrum with a small telescope, succeeded in detecting nearly 600 of these mysterious dark lines. He further noted that one of the most conspicuous of the lines occupied the same place in the spectrum as the *bright* yellow line produced by a Sodium flame.

It was not until 1859 that the true explanation of all these facts was given by Kirchhoff. While observing the spectrum of Sodium, he found that, on placing behind the flame a piece of incandescent lime, the bright yellow line of the vapour became instantly *dark*, and was so seen against the bright continuous spectrum of the lime. The same thing happened to the bright lines of Hydrogen and other glowing gases—all were darkened, or "reversed," as the technical expression is. As the upshot of his experiments, Kirchhoff was thus able to state, as a fundamental law, that substances in the gaseous state had the property of *absorbing*, or blocking out light of the same colour as that which they themselves emitted.

The great secret of the Solar Spectrum was at last revealed, for the dark lines were now seen to be due to the presence of gases in the Sun's atmosphere,



PHOTOGRAPHY AS A MEANS OF DISCOVERY.
The search for new minor planets is now conducted almost entirely by photography. On a photograph they reveal themselves by their motion, which causes them to form short trails on the plate. One of these minor planet trails is shown near the centre of the picture.

cutting out from his light just those colours which they would emit if shining by themselves. Now, the lines in the spectrum of any substance are invariable in their relative positions, and every substance yields an entirely separate and distinctive set of lines. Thus we can identify one by one the elements present in the Sun's atmosphere by comparing the Solar Spectrum with the analysed light of the same substances found on the Earth. In the case of one gas, called Helium, the usual process was reversed, for it was found in the Sun by its spectrum by Lockyer, many years before it could be isolated in our own laboratories.

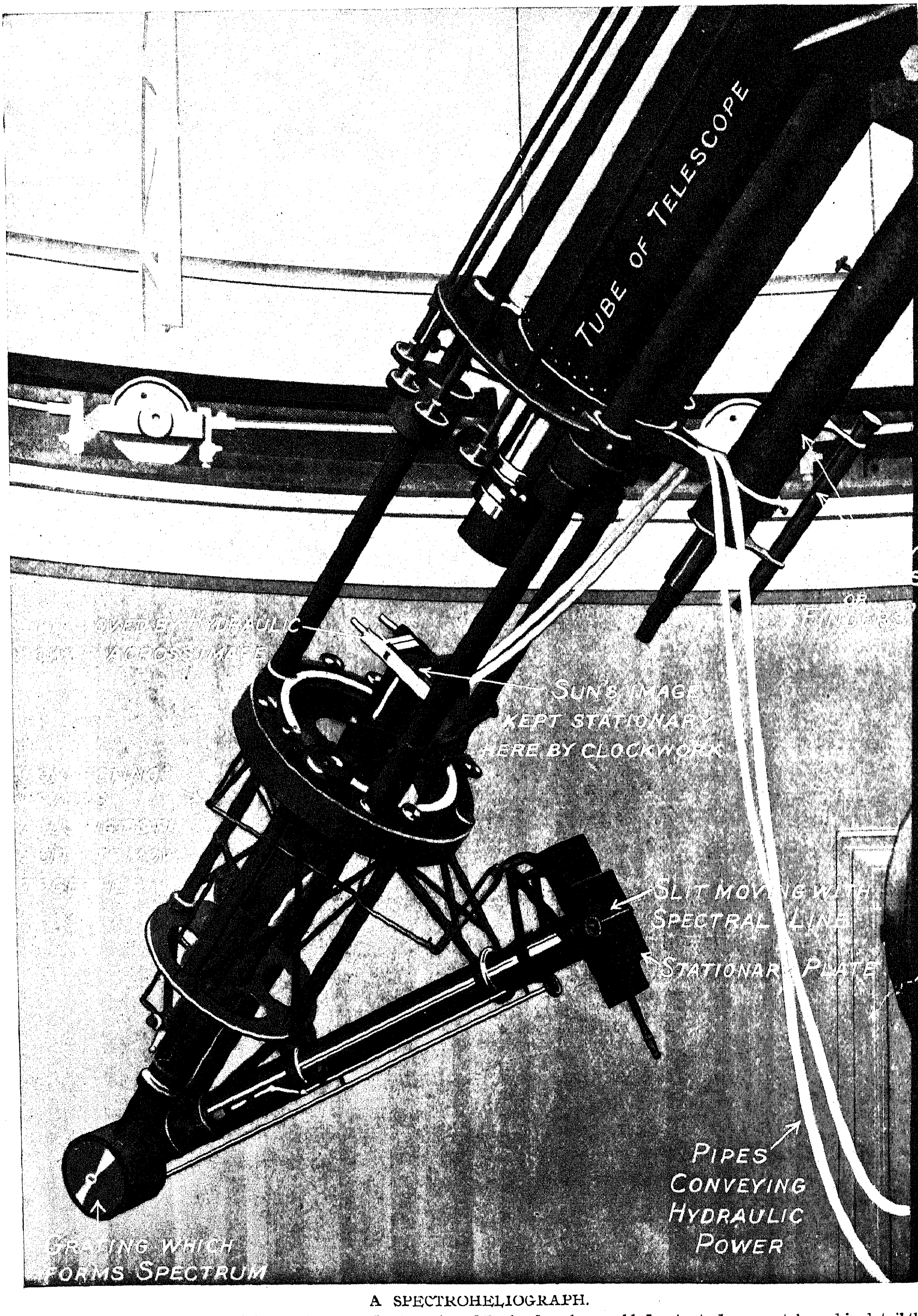
Spectrum analysis, as applied to the heavenly bodies, thus began with the Sun, but it was not long before it came to be applied to the stars. The chief pioneer in this line of research was Sir William Huggins, who began to observe the spectra of stars at Tulse Hill about the year 1860. His observations confirmed the long suspected fact that the stars were comparable in their nature and materials to our own Sun. He identified in them many well-known terrestrial elements and was able to classify them under various types. He was also the first to prove, by means of his spectroscope, the truly gaseous nature of certain of the nebulæ. But the details of his work, and of that of those who came after him, cannot be entered into here. They will be treated fully in other parts of this work. There is, however, one application of stellar spectroscopy, as developed by Huggins, which calls for special mention here, as being directly concerned with the treatment of Light by the spectroscope. It had been pointed out by Doppler that, if a source of Light were approaching an observer, a greater number of light-waves would reach his eye every second than if the body were stationary. In other words the length of each wave would appear to be diminished. Remembering that the colour effect produced by a light-wave depends upon its length, we shall see that every coloured ray in the spectrum will, if the body be approaching, have its tint slightly altered, tending to become more violet than red. Every line, therefore, in the spectrum will be shifted slightly towards the violet end, or, if the body is receding from us, towards the red end. The colour of the body itself, produced by the combined effect of all the rays, will be unaltered, since every ray has moved by the same amount. In every case certain rays are transferred into the invisible portion of the spectrum and a corresponding number emerge into visibility at the other end to fill up the gap created there, so that the full number of rays present in the visible spectrum remains unchanged. By way of analogy, we may picture a bench which just holds ten boys, sitting close together. If an eleventh boy wishes to force himself into the row at one end, say next to number ten, he can do so by pushing all the others along bodily. Number one is forced right off at his end and the total number of boys on the bench remains unchanged.

Photo by] [*R. O. Greenwich*

MOREHOUSE'S COMET, 1908c

Photography has added greatly to our knowledge of the structure of comets and their tails. Very few of these objects are bright enough to show their details clearly to the eye. The "trailing" of the surrounding stars indicates the amount and direction of the comet's motion during the period of exposure.

Making use of this principle of Doppler's, Huggins was able for the first time, by measuring the shift of the spectral lines, to determine the to-and-fro velocities of the stars, or, as it is technically termed,



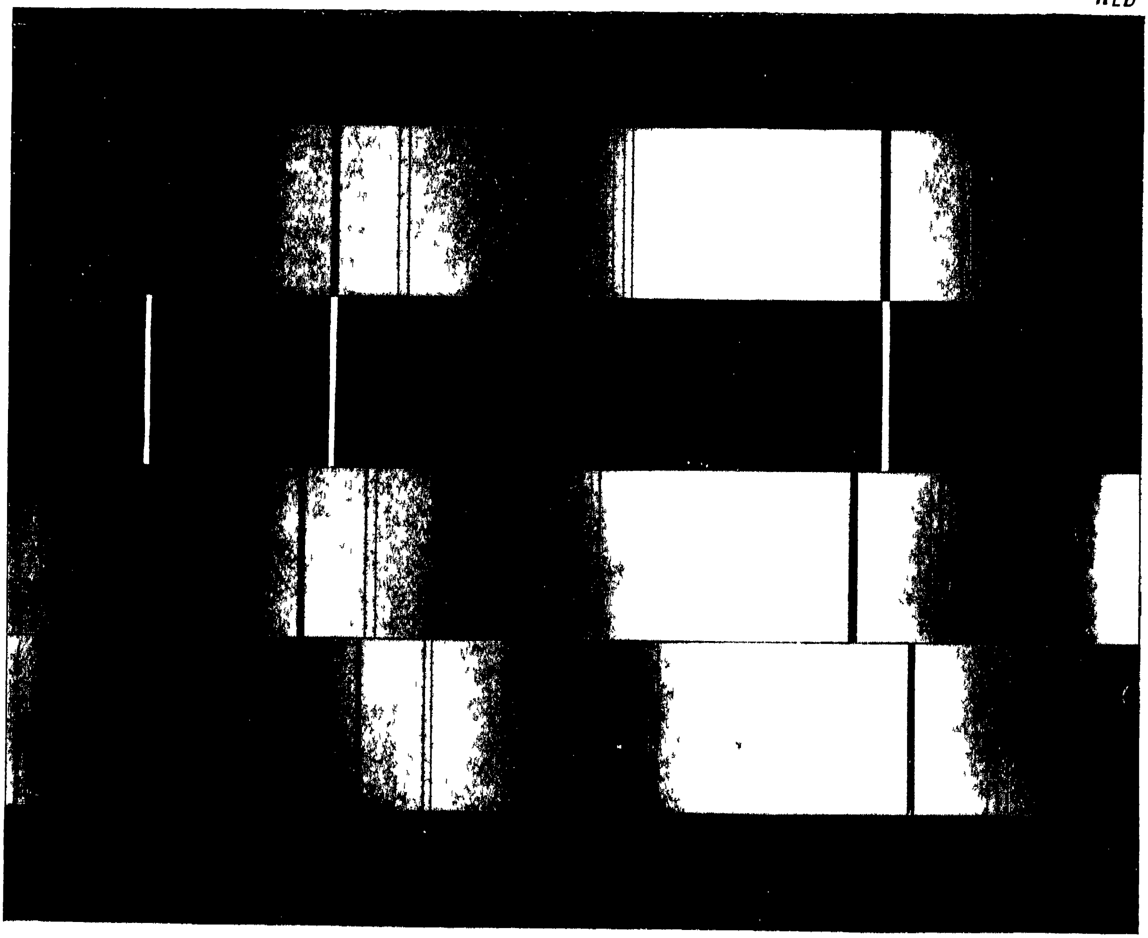
A SPECTROHELIOGRAPH.

This wonderful development of the spectroscope, due to Hale and Deslandres, has enabled us to study separately and in detail the normally invisible gases present in the Sun's upper atmosphere. A spectrum of the Sun is formed in the usual way, by the use of a slit and grating, but, by placing a second slit exactly over one of the dark absorption lines of, say, Hydrogen, all light is excluded from the photographic plate save a single ray due to that element. If the Sun's image is focussed on the first slit, and both slits are moved simultaneously in the same direction, a composite picture is built up, showing the whole of the Hydrogen layer of the

their "line-of-sight" velocities Since then the method has been greatly extended in its accuracy and scope and has added enormously to our knowledge of stellar motions

The uses of the spectroscope are still more extensive than has been indicated in this brief sketch The information it has supplied in various departments of astronomical research will be dealt with in detail elsewhere It will be sufficient here to mention that by its means we have gained knowledge not merely of the materials present in the heavenly bodies, and of their velocities, but also of their temperatures, densities, electro-magnetic conditions, and even their distances from us

VIOLET RED



MOTION REVEALED BY LIGHT

The length of a Light wave is virtually shortened or lengthened if the source of Light is moving towards or away from the observer Thus, every spectral ray (whose colour depends on the wave length) has its tint slightly changed In other words, it moves up or down the spectrum The amount of movement depends on the velocity of the body and is measured by comparison with a spectrum of some terrestrial substance that is present also in the body Our illustration shows (1) the spectrum of a star at rest, (2) the "comparison" or laboratory spectrum, (3 and 4) the spectra of stars approaching and receding respectively

The spectroscopes in use to-day in our observatories differ little in principle from the simple instrument of Fraunhofer, except that nearly all the work is now done by photography The light from a star or other body is focussed on a narrow slit by the object-glass of the large telescope The rays coming from the slit are then made parallel by means of a lens They then pass through one or more prisms, and the resulting spectrum is collected by a lens, which focusses it on the photographic plate In the case of stars the slit is sometimes dispensed with, as the image is narrow enough already In this case the prism is usually placed *in front* of the object-glass, and is then called an "objective-

prism." Obviously the prism will have to be very large if the whole diameter of a big lens is to be utilised, and large prisms are very difficult and expensive to make. Moreover, the length of the spectrum (known as the amount of its "dispersion") is comparatively small except with a very long telescope; and so the method is chiefly employed, with fairly small instruments, for obtaining a general idea, on a modest scale, of the spectrum of a star, or of a group of stars simultaneously. By this means the spectra of stars have been photographed and classified wholesale at the Harvard College Observatory, U.S.A.

The production of a spectrum by means of a prism is, of course, an effect of refraction. But there is another method whereby Light may be dispersed. When a ray of white light passes the edge of an object it is deflected to one side and dispersed by what is known as "diffraction," the red rays most and the violet least. This is not ordinarily detected by the eye, for the resulting colours are

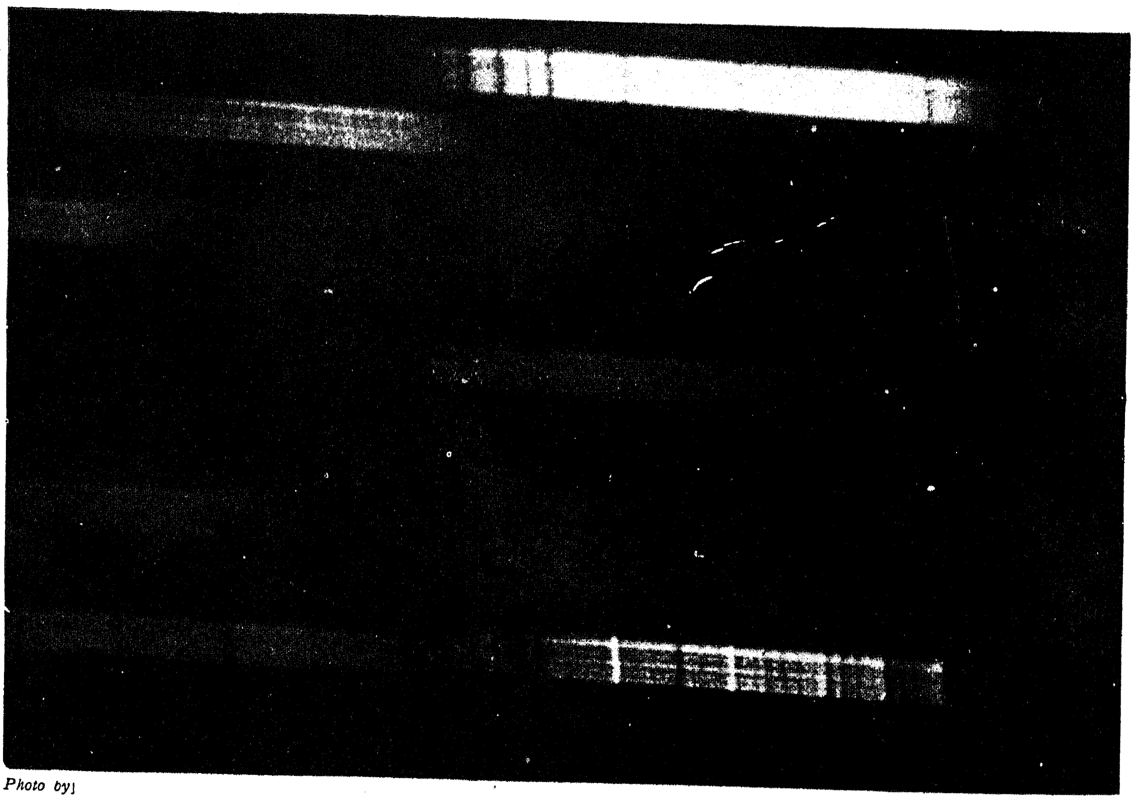


Photo by] [*The Harvard Observatory.*

SPECTRA OF A GROUP OF STARS.

This photograph was taken by a camera fitted with an objective-prism, such as the one shown in an earlier illustration. No slit is used and the spectral lines are formed by allowing the image of the spectrum to "trail" during exposure. Otherwise, the spectra would be narrow lines. The differences in the spectra shown on the photograph indicate variations of stellar type and composition.

"drowned-out," as it were, by the flood of undiffracted light outside the edge of the object. But if a narrow slit is used this does not occur to the same extent; though, as very little light can pass through such a small aperture, the spectrum is very faint. A series of slits, that is alternate clear and opaque spaces, gives a more brilliant result, and the closer and narrower the spaces the finer the spectrum produced. Such an arrangement is called a "grating," and is often used in a spectroscope in place of a prism. The form generally employed is made by ruling a piece of glass with very fine scratches, about 14,000 to the inch, and the light forming the spectrum passes through the glass by "transmission." An alternative form of grating is produced by ruling the lines on a bright metallic surface and the spectrum is then formed by reflection. A familiar example of a coarse reflecting

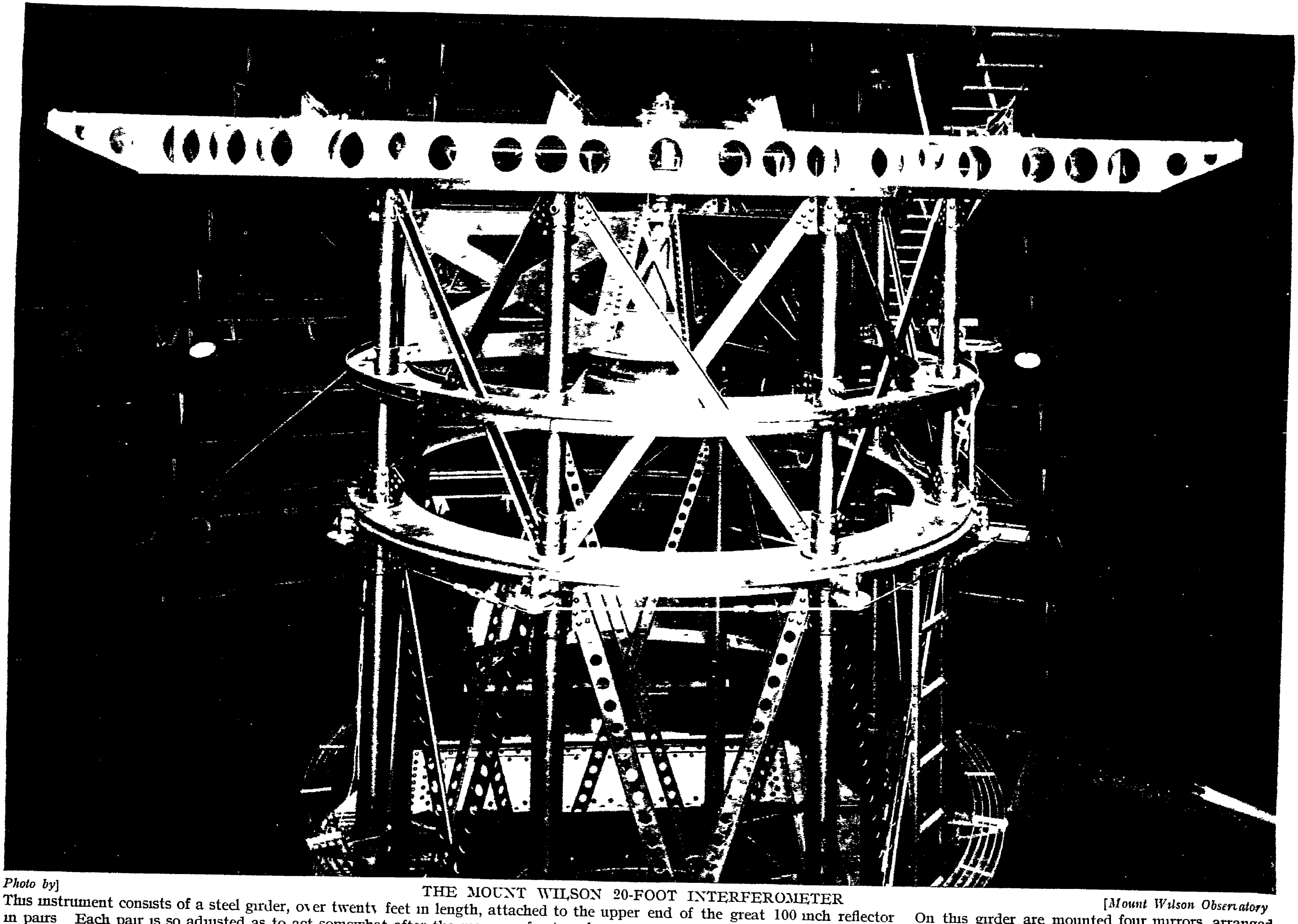


Photo by] [*Mount Wilson Observatory*

THE MOUNT WILSON 20-FOOT INTERFEROMETER

This instrument consists of a steel girder, over twenty feet in length, attached to the upper end of the great 100 inch reflector. On this girder are mounted four mirrors, arranged in pairs. Each pair is so adjusted as to act somewhat after the manner of a trench periscope. The two inner mirrors are fixed, and pass the light on down the telescope. The two outer mirrors, which receive light from the stars, can be moved in or out along the girder. The rays from the two outer mirrors produce "interference" effects which are observable through the telescope, and by noting these effects,

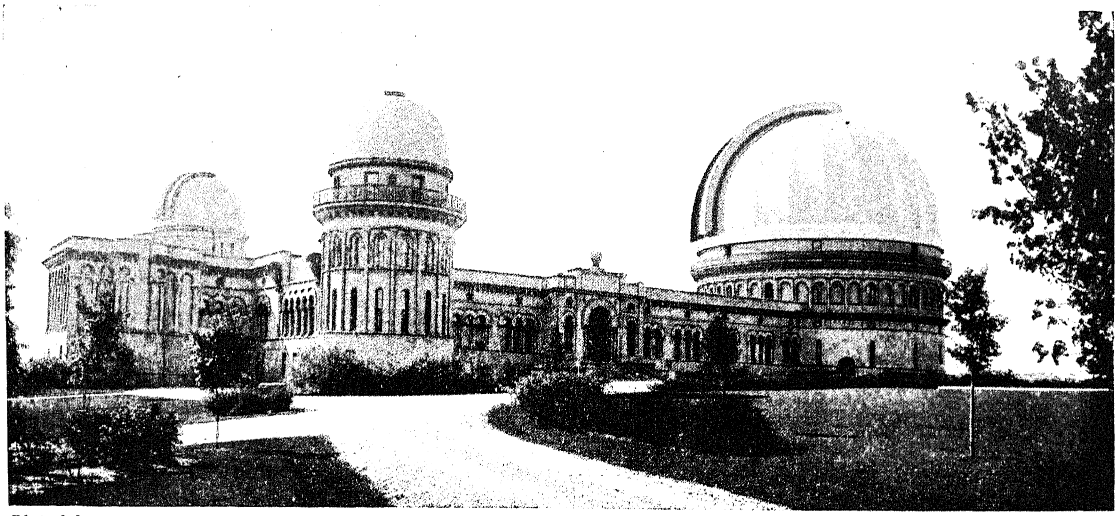


Photo by] [*E. N. A.*

THE YERKES OBSERVATORY, CHICAGO, U.S.A.

Erected in 1895, and equipped with magnificent instruments, the Yerkes Observatory has contributed greatly to the advance of modern Astronomy. The principal lines of work have been direct and spectroscopic photography of Sun, Stars and Nebulæ, and the measurement of close double stars. The great 90-foot dome, covering the 40-inch telescope, will be seen on the right.

grating is the common gramophone record. If one of these is held very obliquely, almost edge-on, and a candle-flame reflected from its surface, the spectral colours will be clearly seen.

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No account of astronomical instruments could in these days be quite up-to-date without some reference to the Interferometer. This instrument was first successfully applied to the purposes of astronomical measurement about thirty years ago by Michelson; but, under his direction, it has been much further developed in the past four years, and has now been made to yield results of the first importance to Astronomy.

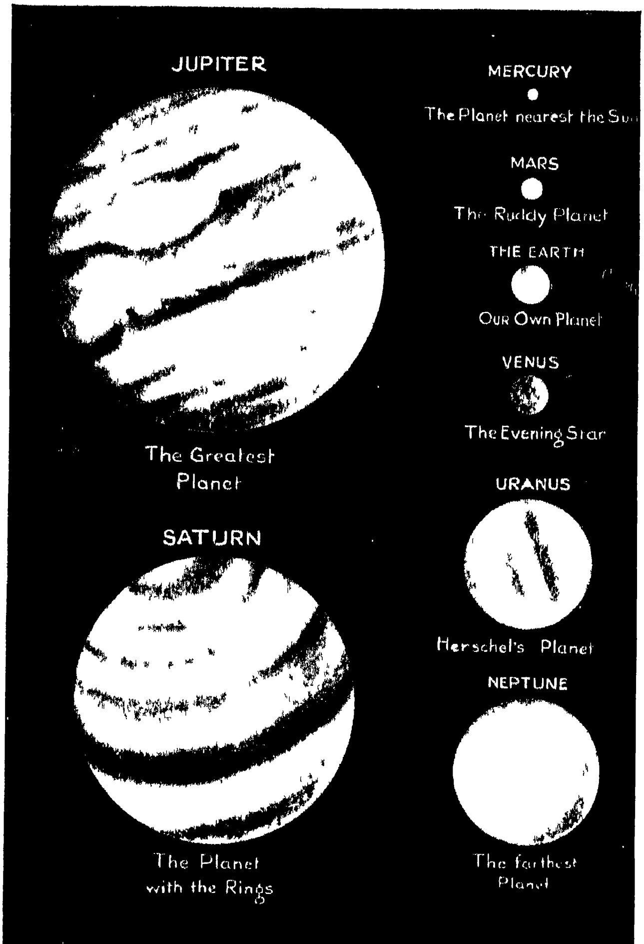
The smallness of the details revealed by a telescope depends entirely upon the diameter of its object-glass. Any telescope has a definite limit below which it cannot render a true picture of fine detail, and if we double the diameter of the glass we shall exactly halve this limit and be able to define detail that is twice as small. Now, it is the rays from the two opposite edges of the lens that are chiefly responsible for resolving detail, so that a large lens, whose edges are farther apart, is more efficient than a small one. We have seen that there are great difficulties in the way of constructing telescopes above a certain size, so that we cannot define clearly, and therefore measure, objects that are below a certain apparent size. But, if we can make use of rays that are farther apart than the diameter of our object-glass we shall virtually increase our ability to reach smaller details, and this is what the interferometer does. The principle employed is similar to that of a trench periscope, which, by means of two mirrors, makes use of rays that would otherwise pass several inches or feet above the line of sight. It will be seen from our illustration that, by the use of two periscopes, rays may be directed down a telescope which were originally anything up to twenty feet apart. In this way the resolving power of the telescope can be greatly increased. This does not actually mean that we obtain a *clearer* view of a small object, as we should do with a larger telescope, but by noticing certain effects produced by " interference " of the rays, we can tell exactly how large a telescope would be required to show the object clearly. By a simple calculation, based on the properties of Light, we can then estimate the apparent size of the body we are observing. In this way the actual diameters of several stars, whose true images are beyond the reach of our telescopes, have been measured at Mount Wilson ; and a larger instrument, with mirrors 50 feet apart, is being made, and will be capable of measuring stars whose discs subtend a still smaller angle.

CHAPTER II

THE SOLAR SYSTEM

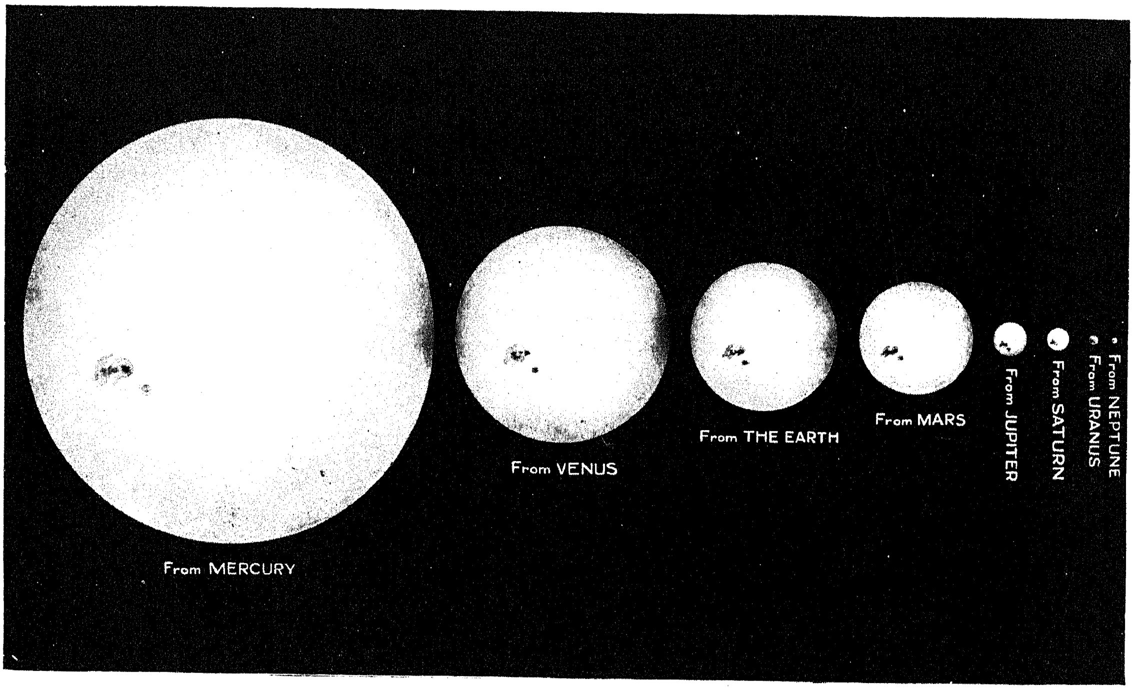
BY A. C. D. CROMMELIN, B.A., D.Sc., F.R.A.S.

WE assume that our readers desire to study the heavens with more care than the mere casual glance that some people bestow on the glittering orbs that bespangle the night sky, when we endeavour to learn their configurations, we find that the great majority of them remain unchanged in their grouping night after night, year after year, and, if we add the experience of others to our own, we may even say century after century. Their place in our sky, indeed, changes rapidly; we have merely to look at some group of stars for a few minutes, and mark its place by some tree, spire or other landmark; we soon notice that it is steadily gliding westward. If we watch the same group the next night, standing ourselves in the same place, we shall find that it gets to the marked position four minutes earlier than the previous night. This daily change of four minutes mounts up to two hours per month, so that a few months brings about a complete alteration in the star-groups visible in the evening sky. When we have watched them through a whole year, we note that they repeat the same positions as 12 months earlier. There is thus a daily and a yearly shift, but both of these belong to our Earth, not to the stars themselves; the Earth has, in fact, two movements—a daily spin, which is accomplished in 24 hours all but four minutes, and a yearly motion round the Sun. This latter movement causes the Sun to occupy different positions in the heavens month by month; the stars seen at night, which are those opposite to the Sun, or nearly so, also change from month to month. Throughout these changes the stars continue to show the same grouping among themselves. This applies to the great bulk of them, but there are exceptions. If we mark the place of the Moon among the stars, we shall quickly find that it is moving among them. The motion is always in the same direction, and through a certain group of 12 constellations, forming the Zodiac, which we shall do well to study carefully and commit to memory. The Moon completes its tour of the heavens in a little more than 27 days, but the time required to bring it back to the same phases as at first (Half-Moon, Full-Moon, etc.) is two days longer, or 29½ days. The Moon is not the only moving orb in the 12 constellations of the Zodiac. We have already drawn the inference that the Sun goes round them once a



COMPARATIVE SIZES OF THE PLANETS

This picture shows the great difference in size between the planets. The four giant planets have very extensive atmospheres of clouds and vapours, and do not exceed the Earth in mass to nearly the same extent that they do in bulk. The belts on Jupiter, Saturn, and Uranus, result from rapid rotation.



COMPARATIVE SIZES OF THE SUN AS SEEN FROM THE PLANETS.

Neptune, the farthest planet, is nearly 80 times as far from the Sun as Mercury, the nearest, and consequently receives less than one-sixty-thousandth of the light and heat. If the outer planets were dependent on the Sun alone for their heat they would be perpetually frostbound.

year; besides these two, there are five other bright orbs that change their places among the stars. The whole seven were known as the planets (Greek, "Wandering Stars"), but nowadays the Sun and Moon are rarely included under this title. We cannot continue our star-watch for many weeks without picking some of them up. The most brilliant of all can be instantly distinguished from a fixed star by its lustre alone. This is Venus, the beautiful morning and evening star. It is never very far away from the Sun, and is seen in the west after sunset for several months in succession, then after a brief interval it becomes a morning star for several months; its complete cycle of changes lasts for a year and seven months. Mercury imitates the behaviour of Venus, but its cycle of changes is much briefer, lasting only four months; also it is much less brilliant, and we shall not pick it up without consulting the almanac. Jupiter comes second in brilliancy among the planets, and is much brighter than any fixed star; it can be seen for several months every year; first as a morning star, then as an all-night star, and finally as an evening star. Its motion among the fixed stars is slow, and it takes 12 years to go round the sky. It therefore remains a year in each constellation. The two remaining orbs can be easily distinguished by their colours, Mars being of a fiery orange, while Saturn is a dull yellowish white; also it moves much more slowly through the stars, taking nearly 30 years to go round the sky, whereas Mars takes less than two.

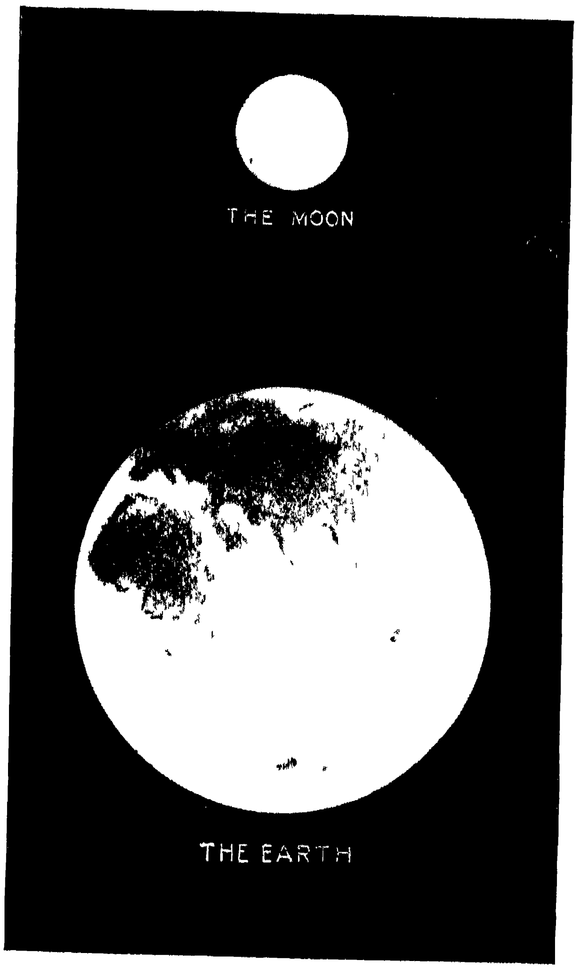
It is a natural and correct inference to draw that all these moving orbs are much nearer to us than the fixed stars are. They form, together with our Earth, a family of worlds isolated in space, to which the name Solar System, or Sun's Family, is given. The study of this family will occupy several chapters; the present one deals with them as a connected group, and afterwards they will be studied singly.

The changing phases of the Moon are due to its being a dark world like our Earth, simply shining by reflecting back the sunlight that falls on it. When nearly in the same direction as the Sun, it turns only a small portion of its bright side to us, appearing as a thin crescent. But as it moves on we see more and more of the bright side, till the whole disc is bright, when it is opposite to the Sun. The two inner

planets, Mercury and Venus, show phases in the telescope like the Moon, proving that they are dark bodies like our Earth and we know that the same is true for Mars. It is this kinship with our Earth that gives the planets such a special interest to us. The Sun and the fixed stars, which shine by their own light, are far hotter than the hottest furnace, and no life can be pictured in them, though they serve to make life possible on worlds that they light and warm.

The planets resemble our Earth in other respects; like her they spin on their axes, and so have day and night, also the larger ones have atmospheres, whose presence is of course essential for habitability. Mars has a scanty atmosphere, which is, however, dense enough to support clouds, from which rain and snow descend upon the surface. Mercury and the Moon are practically devoid of atmospheres, and the same is probably true of all small worlds. The gases forming an atmosphere are always trying to escape, and it needs a strong attraction—stronger than that which the small planets possess—to hold them fast. On the very large planets there is another obstacle to the presence of life; they probably began their career in a much hotter state than the Earth, and as large bodies cool very slowly, they are not yet cool enough to be inhabited. Thus, the only worlds outside our own that we can plausibly imagine to be the abodes of life are Venus and Mars.

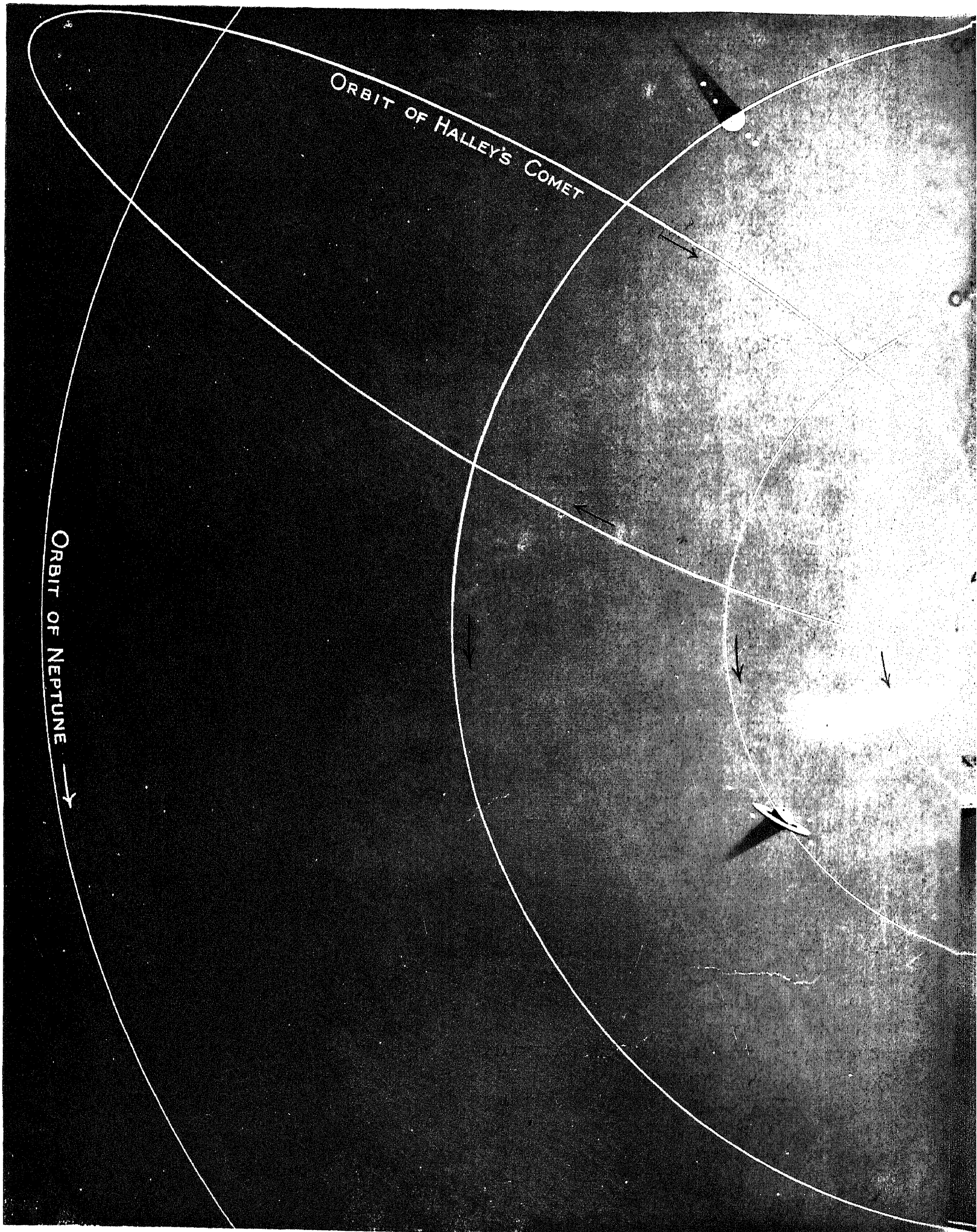
The Solar System consists of a great central orb, the Sun, and a numerous retinue of attendant worlds travelling round it. The Sun outweighs their united mass about 700 times; we can see two strong reasons for this great preponderance: first in order that it should continue to supply light and heat to its retinue during the vast periods during which their habitability continues; secondly, that its attractive power should so far exceed that of its attendants that these should not disturb each other's movements to a serious extent; any great change in their paths would be prejudicial to the well-being of their inhabitants. Also, if the planets were comparable with the Sun in size, they would not cool sufficiently for habitability till it had long passed its efficiency as a dispenser of light and heat.



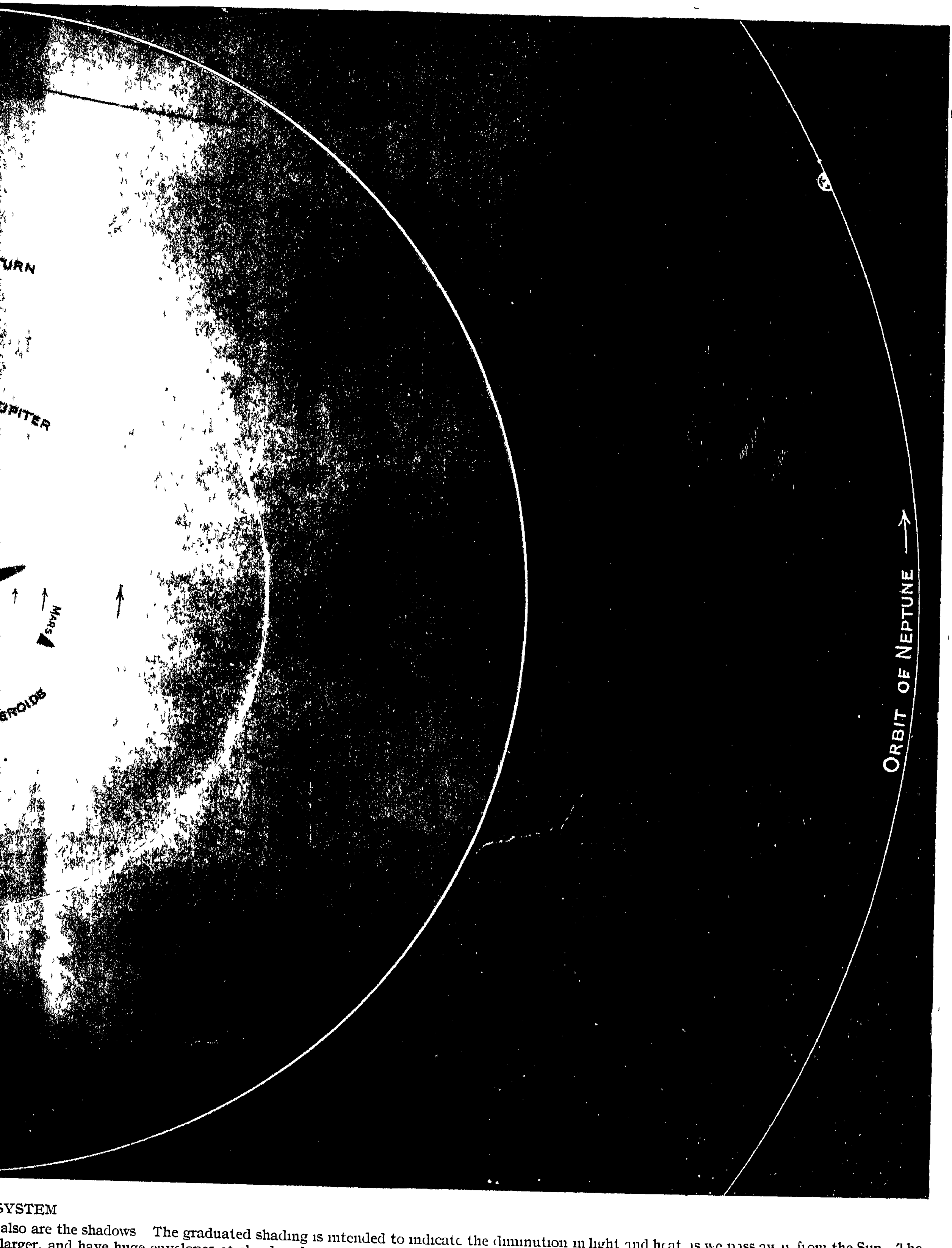
SIZE OF THE MOON COMPARED WITH THE EARTH

The diameter of the Moon is 3/11 of the Earth's, consequently the surface is 1/13½ and the bulk 1/49 of the Earth's. But its materials are less tightly packed, so that it weighs only 1/81 of the Earth.

We may divide the planets into three groups; that nearest the Sun is called the group of terrestrial planets since all its members resemble the Earth in having cooled sufficiently to have solid surfaces. The Earth is the largest of the group, and the third in distance from the Sun; its neighbour, Venus, is almost as large, but the others are much smaller, Mars, the outermost member, having one-ninth of the Earth's mass, Mercury, the innermost, only one-twenty-seventh, and the Moon, which we may regard as a member of the group, one-eighty-first or one-third of that of Mercury. A study of these worlds shows that a certain size is necessary for a planet to be inhabited; the small worlds Mercury and the Moon are airless, and Mars has but a scanty atmosphere, while that



The paths of the planets round the Sun are here shown in their true proportions, but the discs representing the planets are necessarily much
asteroids or minor planets divide the planets into two groups, the inner group is composed of cool, solid bodies, like the Earth; the
than those between the inner planets. If this were not so they would greatly disturb each other's motions. Besides the planets
ellipses. The path of one comet (Halley's) is shown; it passes inside the orbit of Venus and outside that of Neptune, the great
direction. Comets when near the Su



SYSTEM

also are the shadows The graduated shading is intended to indicate the diminution in light and heat as we pass away from the Sun The
larger, and have huge envelopes of cloud and vapour round them It will be seen that the spaces between their orbits are much greater
d meteor swarms travel round the Sun While the paths of the planets are almost circular, those of the comets are elongated ovals or
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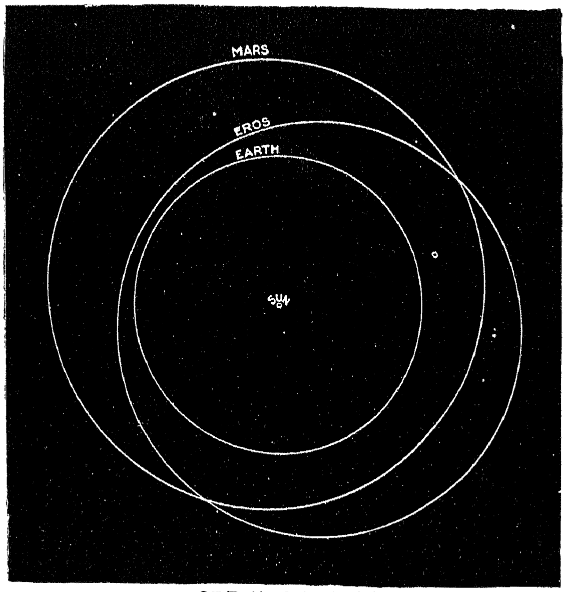


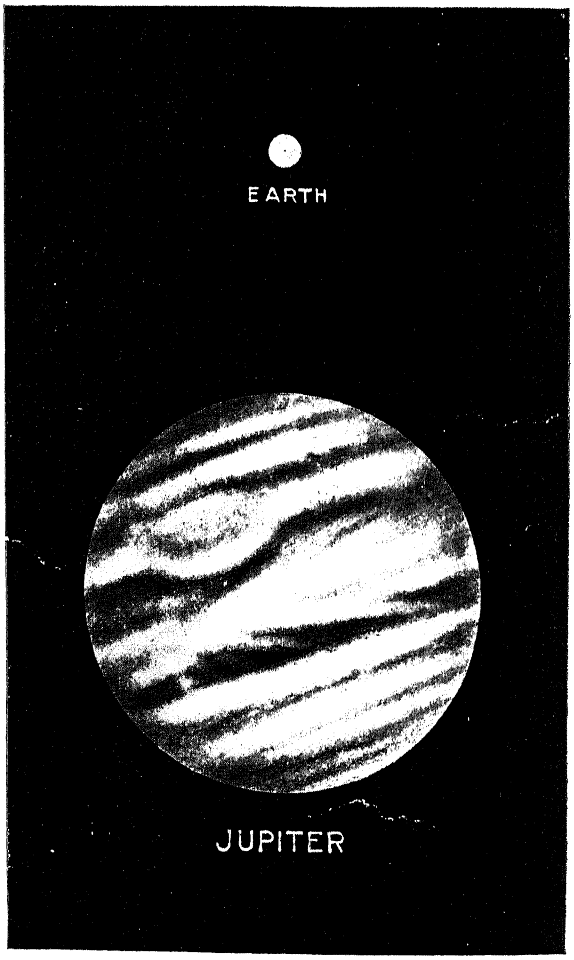
ORBIT OF EROS.
Diagram of the orbits of the Earth, Mars, and Eros; the last named is a minor planet whose path comes within 15 million miles of the Earth's. Its near approaches, of which the next happens in 1931, are used for finding more accurately the Sun's distance.

of Venus is comparable with our own in extent.

The outer group of planets consists of much larger bodies, which appear to be still in a heated state; their surfaces are probably molten, but surrounded by very thick layers of clouds and vapours, which is all that we are able to study. Jupiter outweighs the Earth 318 times, Saturn 95 times, Uranus and Neptune 15 and 17 times. The huge orb of Jupiter weighs nearly $2\frac{1}{2}$ times as much as all the other planets put together; yet it would take more than 1,000 Jupiters to balance the Sun. The giant planets exceed the Earth in bulk still more than they do in mass, but their materials are much less tightly packed, which is one of the reasons for concluding them to be hot. The spaces between their orbits are much greater than those of the inner planets; thus Jupiter is five times our distance from the Sun, while the other three are respectively two, four, and six times Jupiter's distance. This wide spacing is necessary for the stability of their orbits; serious disturbances of their motion would arise if they were nearer each other.

Rapid rotation also characterises the giant planets. The three first are known to rotate in about ten hours; as a consequence their equators bulge out to a notable extent; thus Jupiter's equatorial diameter exceeds the Polar one by 6,000 miles. Owing to distance the bulge cannot be clearly seen in the case of Neptune, but its effect is shown in the motion of Neptune's satellite. The tendency of clouds to lie in belts parallel to the equator is plainly seen in Jupiter and Saturn, and suspected in the other two. It is a result of the rapid spin and of the extensive atmospheres. Matter coming up from a lower level would have a slower speed (having a smaller circle to describe), and so would be left behind.

These planets have all families of satellites going round them. At present nine are known



COMPARATIVE SIZES OF JUPITER AND THE EARTH.
Jupiter exceeds the Earth 11 times in diameter, 120 times in surface, and 1300 times in bulk. But its materials being less tightly packed, probably owing to heat, it outweighs the Earth only 300 times. The oval patch on Jupiter is the "Red Spot."

for Jupiter, nine for Saturn (a tenth, Themis, was announced, but is not completely verified), four for Uranus, one for Neptune The largest moons of Jupiter and Saturn are much larger than our Moon, and fall little short of Mercury in size, but the small ones are less than 100 miles in diameter These tiny worlds lead us on naturally to the third group of planets the asteroids or planetoids, a family of thousands of very minute worlds whose orbits lie in almost all cases between those of Mars and Jupiter,

DRAWING OF MARS IN 1909 BY E M ANTONIADI

This picture was drawn by E M Antoniadi, with the large telescope at Meudon, near Paris Like most astronomical drawings it is inverted The white patch near the upper right-hand edge is the South Polar Cap, supposed to consist of snow Its dark border is supposed to be water resulting from its melting The curved dusky marking near the bottom of the disc is the Syrtis Major, the plainest marking on the planet after the Polar Cap The dusky regions are conjectured to be vegetation, while the lighter regions at the bottom and left (which appear orange in the telescope) are probably deserts

though these limits are transgressed in both directions by a few of them Over a thousand are now actually known, and every year 30 or 40 more are added, so that it is estimated that there may be some 50,000 altogether The largest, Ceres, was discovered by Piazzi on the first day of the nineteenth century

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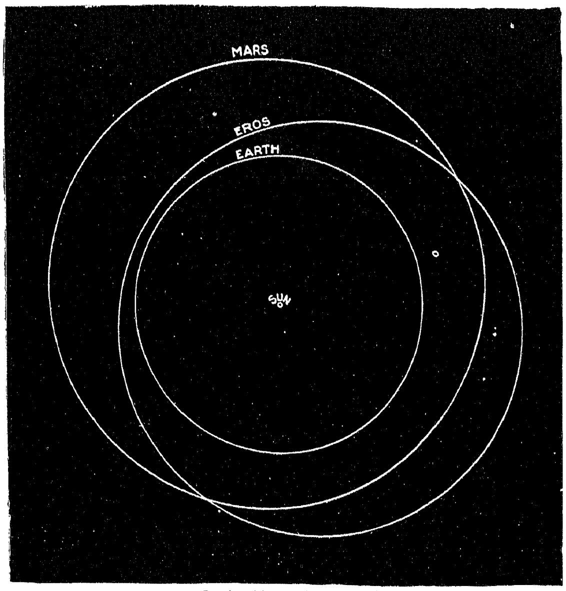

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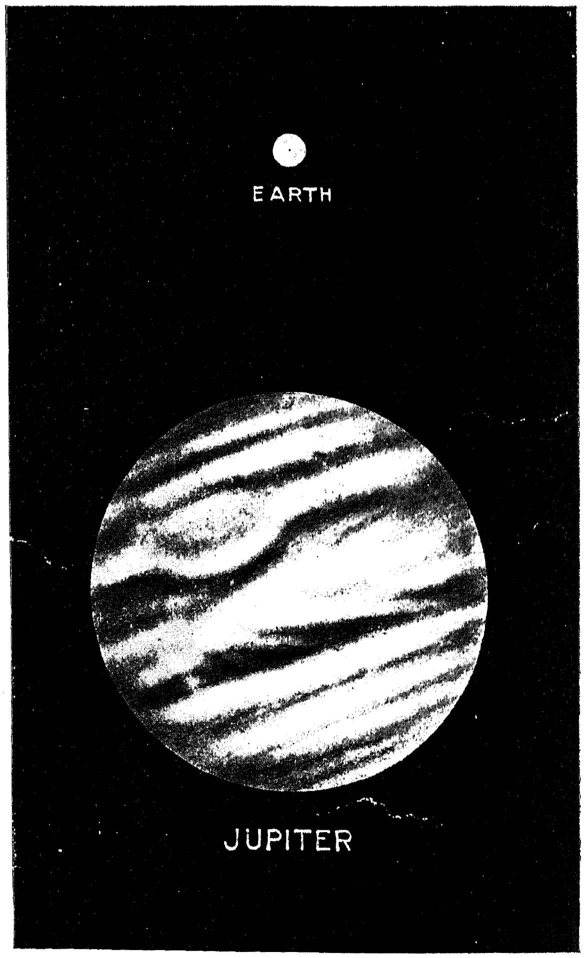

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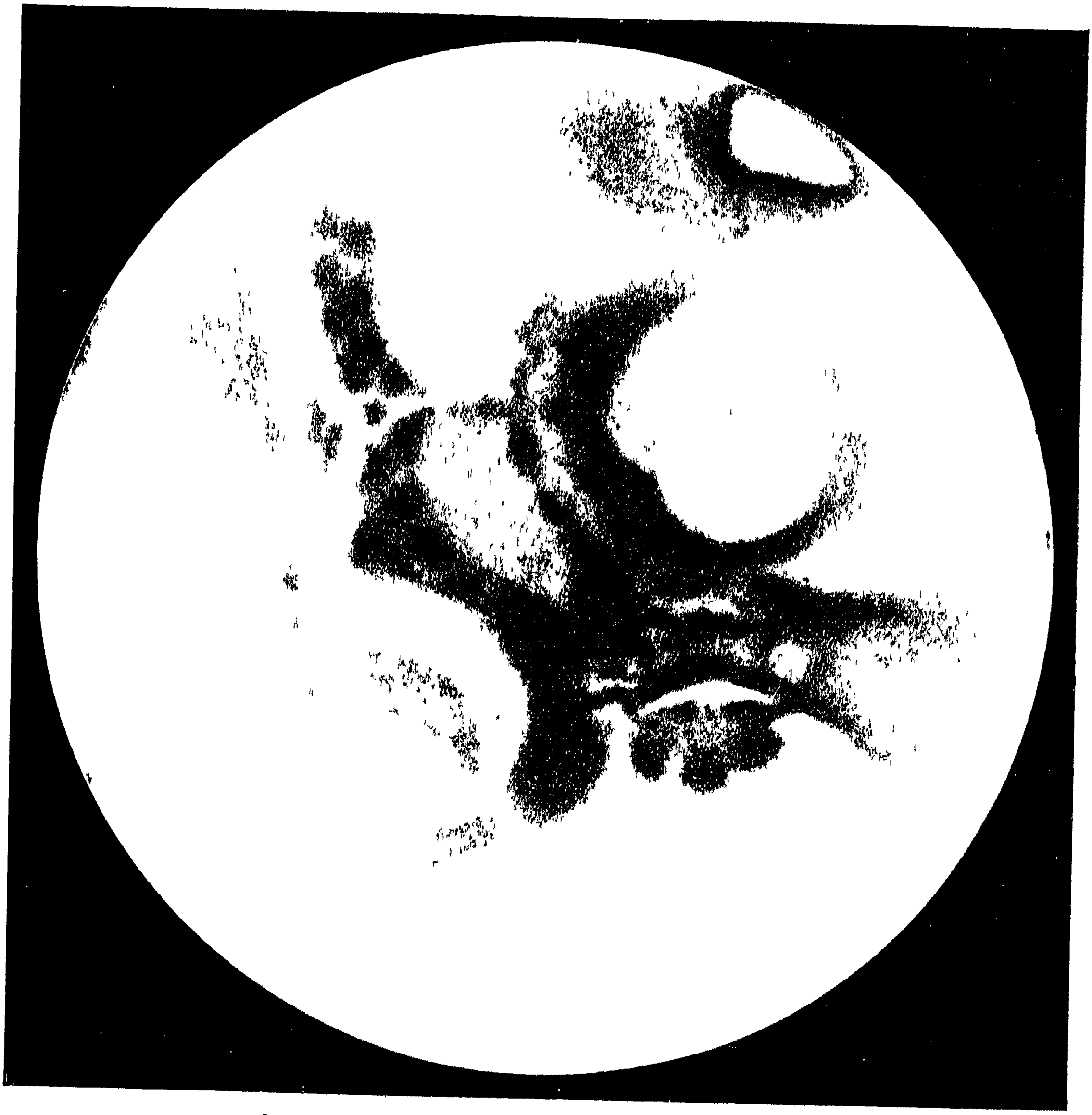
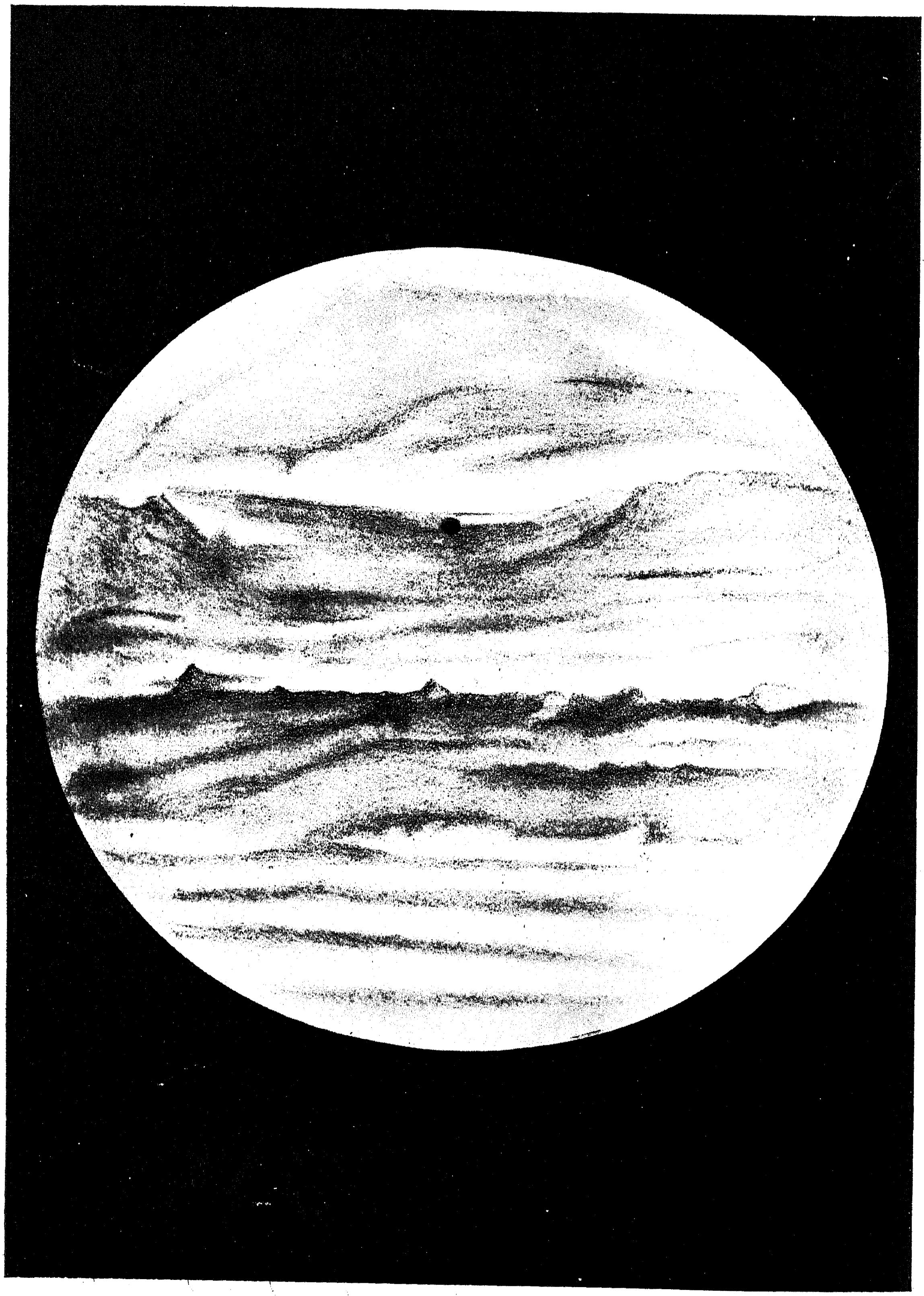


DRAWING OF MARS IN 1909 BY E. M. ANTONIADI

This picture was drawn by E. M. Antoniadi, with the large telescope at Meudon near Paris. Like most astronomical drawings it is inverted. The white patch near the upper right hand edge is the South Polar Cap, supposed to consist of snow. Its dark border is supposed to be water resulting from its melting. The curved dusky marking near the bottom of the disc is the Syrtis Major, the plainest marking on the planet after the Polar Cap. The dusky regions are conjectured to be vegetation, while the lighter regions at the bottom and left (which appear orange in the telescope) are probably deserts.

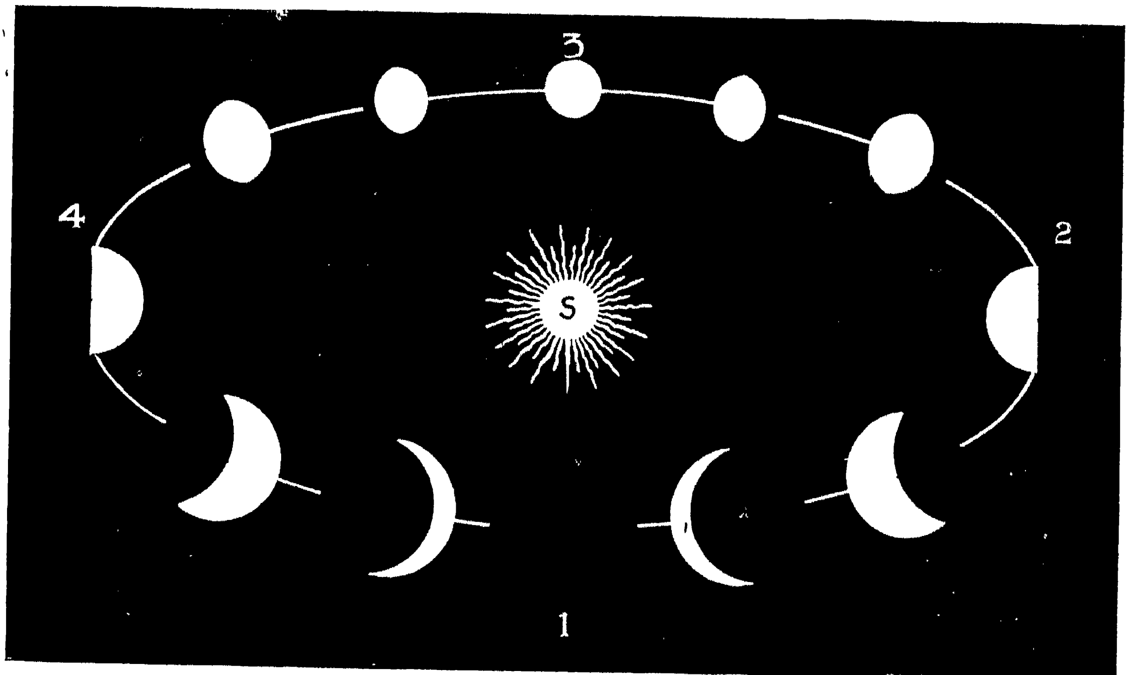
though these limits are transgressed in both directions by a few of them. Over a thousand are now actually known, and every year 30 or 40 more are added, so that it is estimated that there may be some 50,000 altogether. The largest, Ceres, was discovered by Piazzi on the first day of the nineteenth century



DRAWING OF JUPITER.

This is a very interesting telescopic object. It spins round its axis in ten hours; this rapid motion causes its equator to bulge out, and also produces currents in its atmosphere which causes its clouds to form into belts parallel to the equator. The shadows of its four large satellites frequently cross the disc as black spots (one is shown). The satellites themselves appear as bright spots when near the edge of Jupiter, but as dark ones when near the centre, since the latter region of the planet is brighter than the former.

Its diameter is about 450 miles, a fifth of that of the Moon, which means that its bulk and mass are less than one-hundredth of hers. Since the great majority of them are far smaller than Ceres, it is doubtful whether their united mass would equal that of the Moon, so that even if united they would only form a tiny planet. There is reason to think that the smaller ones are not spherical in shape, but angular masses of rock; this would account for the fact that their light is often found to vary rapidly as they turn and present more or less of their surface to us. In the case of large bodies, like the Earth, or even the Moon, the mutual gravity of their components is far stronger than the force of cohesion, which holds the particles of a solid body together, so that any large departure from a spherical form would be quickly corrected. But in worlds whose diameter is only a few miles, the force of cohesion would be far stronger than gravitation, so that the body would retain whatever irregularity of form it had initially. It is also of interest to note that the axis of rotation of such irregular fragments would change fairly rapidly inside the body, which is probably the reason why the changes of light of Eros, the asteroid that approaches the Earth most closely, are so difficult to reduce to rule.



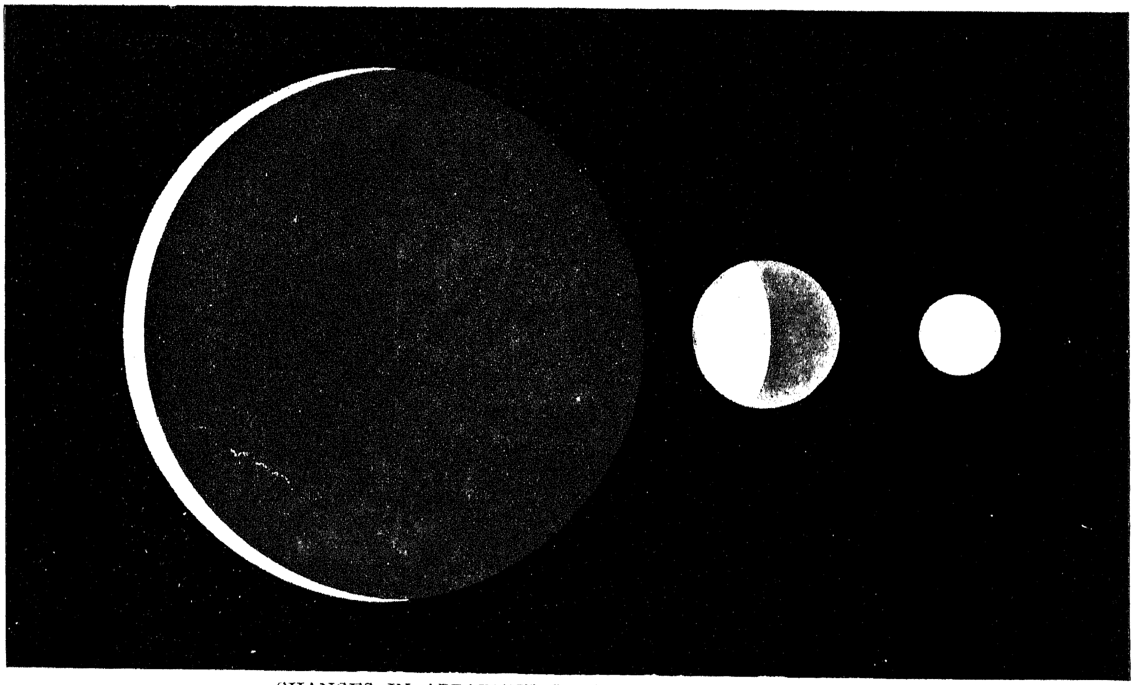
CHANGES IN APPARENT SIZE AND SHAPE OF MERCURY

When Mercury is nearly between the Earth and Sun it is nearest to us and so appears largest. But it then turns its dark face to us. As it recedes from us it becomes smaller but turns more and more of its bright side towards us, so that it appears first as a crescent, then as a half disc, while when nearly behind the Sun it would appear a full disc, but small.

Besides considering the sizes of the planets, it is also important to consider the size of the Sun as seen from them. This varies enormously, Mercury seeing a disc seven times as large as the Earth—as the heat increases in the same proportion, this cause alone would render it uninhabitable. Mars sees a disc less than half the size that we do; the thin air of Mars allows the Sun's heat to reach the surface somewhat more readily than with us, but it also permits it to escape freely, so that terrible frosts must prevail at night. The giant planets receive a very small amount of light and heat: Jupiter one-twenty-fifth, Saturn one-hundredth, Uranus one-four-hundredth, Neptune one-nine-hundredth. In each case the comparison is with the amount received on Earth. But we may well imagine that if these planets are intended to support life in the future, they will draw their supplies of heat from their own interiors and depend on the Sun for light alone.

The whole family of worlds, large and small, that we have described, travel round the Sun in the same direction, and in nearly the same plane or level, though there are a few exceptions to this last

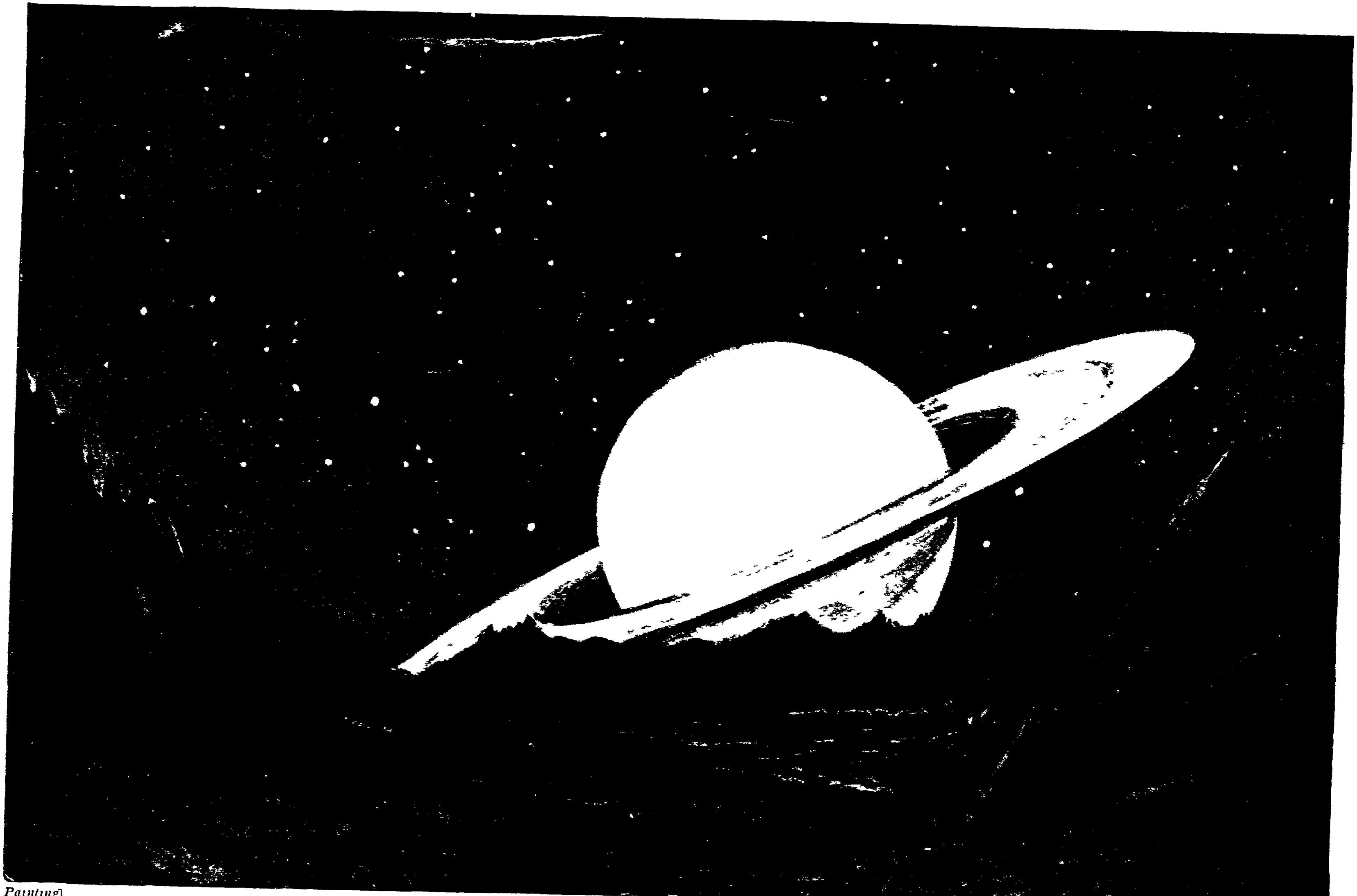
point among the small planets, which may plausibly be ascribed to the perturbing action of their giant neighbour Jupiter. The facts indicate with moral certainty that the formation of the planets was not a series of isolated actions, but a single mighty process; we cannot hope to attain certainty in our answers to such problems, but it is a natural tendency of the human mind to attempt their solution. The earliest attempt that need be mentioned was that of Laplace, who conjectured that the whole Solar System had once been an immense sphere of exceedingly attenuated gas, in slow rotation. It gradually condensed under its own attraction, a result of which was to make it rotate more rapidly. At length a stage was reached at which the equatorial ring was thrown off, which subsequently condensed into the outer planet: successive repetitions of the process accounted for all the planets, while finally the central gaseous mass condensed into the Sun. Dr. Jeans has shown that a process like this appears to be taking place in some of the gaseous nebulæ, but that the planets of our System can never have been mere masses of gas, their



CHANGES IN APPARENT SIZE AND SHAPE OF VENUS.

Venus undergoes changes in size and shape, as seen from the Earth, that are analogous to those of Mercury (*see* page 79) but are still more accentuated, since its least distance is smaller and its greatest distance farther. The point at which Venus appears brightest is a little nearer to us than the point where it appears as a half-disc. Venus can often be seen in daylight at such times, and casts faint shadows at night.

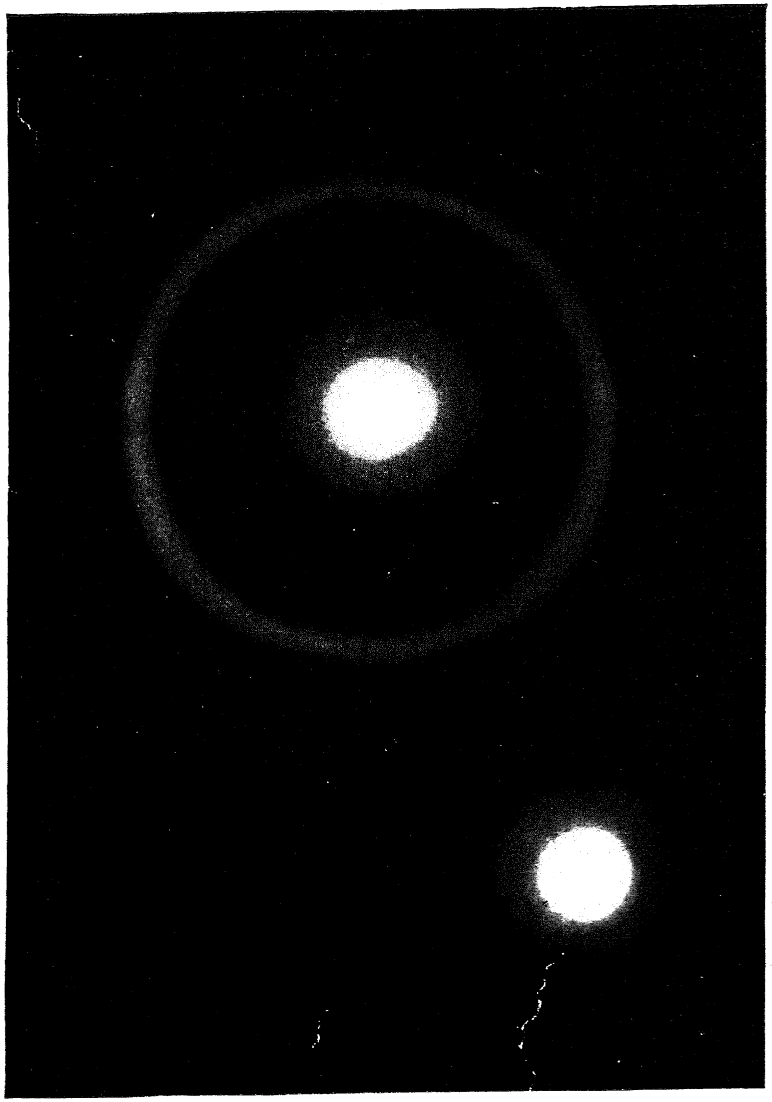
attractive power being in all cases too small to prevent the gas from dissipating into space—a mass approximating to that of the Sun is required for this purpose. It is inferred that the planets must have been solid or liquid from the first, and it is conjectured that the near approach of another sun raised great tidal waves in the Sun: streams of matter are supposed to have been ejected from it; condensations would form in these streams, which would be the nuclei round which other particles would gradually collect till the planets were built up. To account for the varying sizes of the planets the supposition is made that the rapid motion of the particles near the Sun made aggregation more difficult, while in the region outside Jupiter the material began to get scarcer, but no quite satisfactory explanation of the immense disparity of the masses of the planets has yet been attained. The theory also helps to explain two other features of the system. The Zodiacal Light, shown on page 88 is an ill-defined beam of light seen in evening or morning not far from the Sun's place: it almost certainly



Painting] [By the Abbé Moreux

SATURN AS SEEN FROM MIMAS, ITS NEAREST SATELLITE

The little moon Mimas goes round Saturn in 22 hours, and an observer on it would see Saturn change from Full to New, and then back to Full in that time. But as Mimas always turns the same face to Saturn, the latter would remain fixed in its sky throughout these changes. We do not know what the surface of Mimas is like, but the artist has assumed a surface like that of our Moon. One small departure from fact has been made for pictorial effect. Since Mimas travels in the plane of the ring, the latter should have been shown edgewise, as a thin bright line. The great gap, some 2,000 miles wide, is seen in the middle of the ring, also some other narrow gaps, and the dusky crepe ring on the inside.

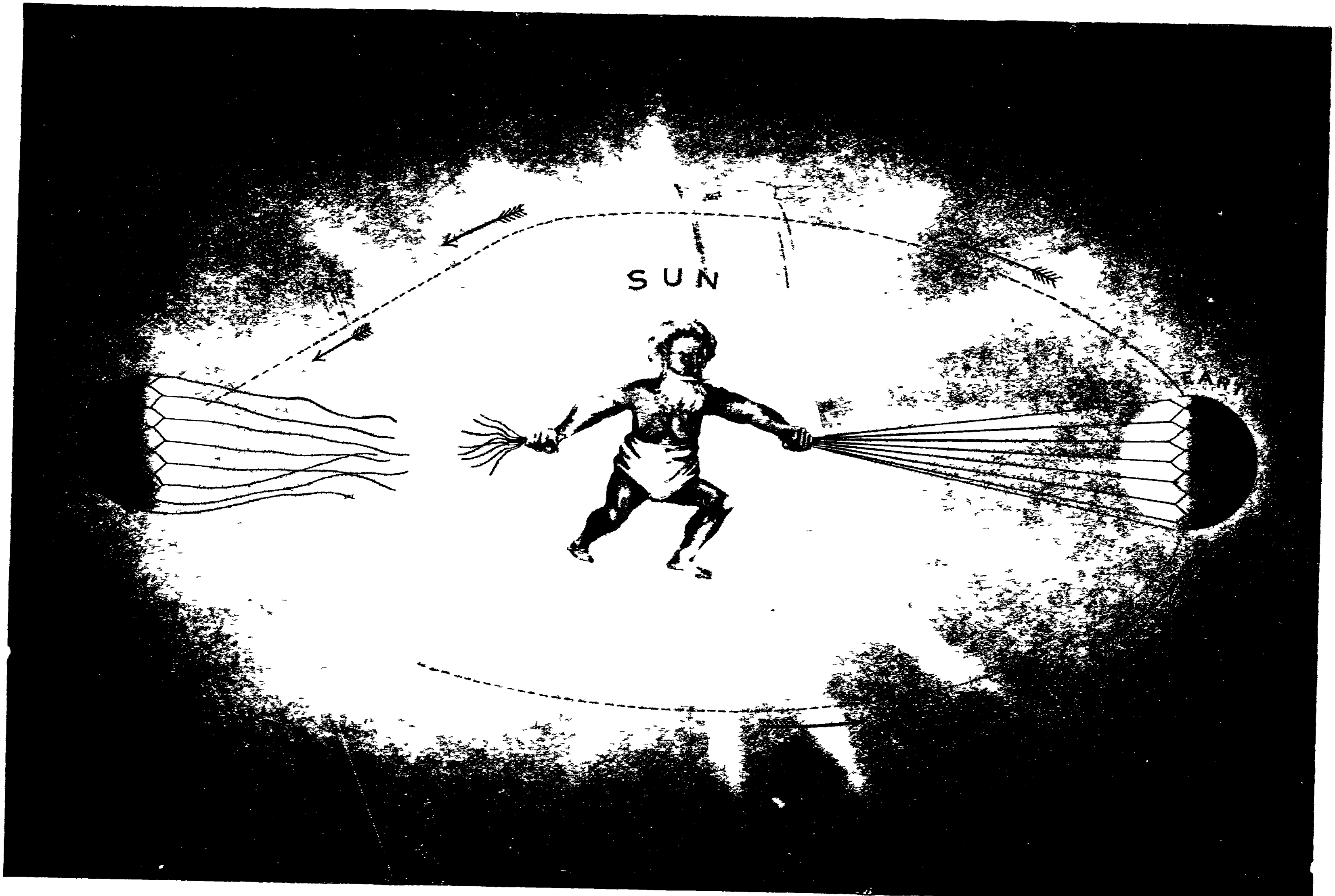


LAPLACE'S NEBULAR HYPOTHESIS.

An attempt is here made to visualise this hypothesis. A huge mass of gas is supposed to be rotating and contracting. Its spinning gets quicker, causing it to send off rings from its equator. The picture shows one such ring; the mass outside this is supposed to have condensed from an earlier ring. This theory is not now [illegible]

THE PLANETESIMAL HYPOTHESIS.

This was suggested by Moulton and Chamberlin. They suppose another sun to have approached ours ages ago, raising great tidal waves, which left the Sun in the form of two spiral arms. Condensations forming in these, and collecting more matter from the dust-streams around them, became the planets.



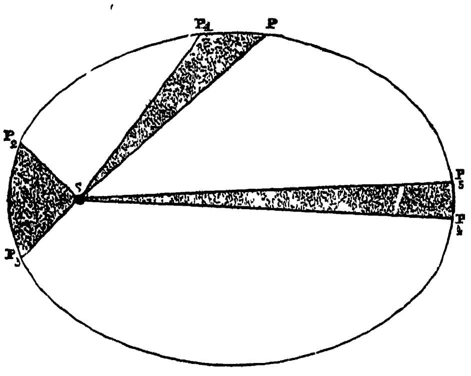
THE SUN'S PULL ON THE EARTH

It needs an incessant giant pull on the part of the Sun to keep the planets circling round him So strong is his pull on the Earth that it has been calculated that if a set of wires were substituted for the invisible force, they would need to cover the whole Earth as thickly as the blades of grass on a lawn The picture personifies the pull as exerted by a giant in the Sun holding the Earth by cords The planet on the left is represented as having broken loose, to illustrate the disastrous consequences to the planets if the Sun ceased to pull

Earth over Boadicea's Statue. | Mars over Scotland House. | Jupiter over Turret of County Hall. | Saturn over Adelphi Terrace. | Uranus over St. Clement's Dane. | Neptune over St. Paul's Cathedral.

PLANETARY DISTANCES COMPARED WITH LONDON LANDMARKS.

As a help to realise the distances of the outer planets, they are here compared with familiar objects in London. The Sun is supposed to be in the Clock Tower, at the point marked X. Neptune, the outer planet, is placed at St. Paul's, while the other planets have suitable landmarks assigned. For greater convenience the bend in the river has been straightened. On the scale of a mile from the Sun to Neptune the nearest fixed star would be in New Zealand.



LAW OF EQUAL AREAS

Kepler's second law states that planets and comets sweep out equal areas in a day at all parts of their orbits They have therefore to move more quickly when near the Sun

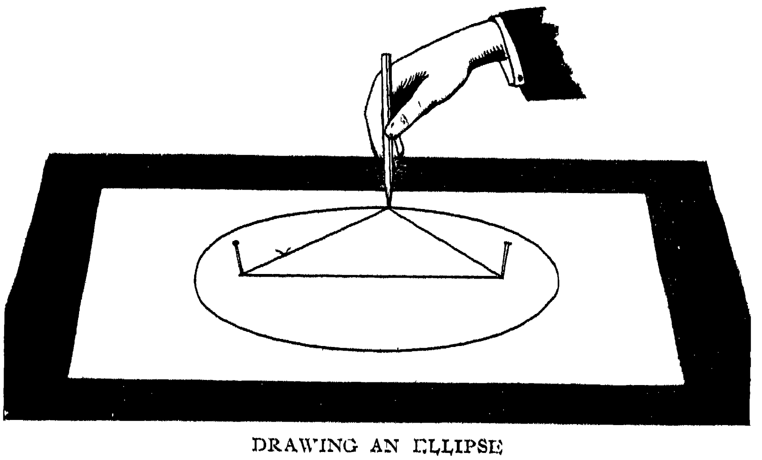
indicates the presence of clouds of dust travelling round the Sun, the remnants of the dense streams that have been mentioned The other feature is the Comets, which are believed to be aggregations of meteors, or lumps of iron and other substances, having quantities of gas shut up in them When they approach the Sun its heat, and perhaps also electrical action, cause the gases to stream out into splendid tails that are sometimes visible They go round the Sun in long narrow paths, and are visible to us only for the short time during which they are near it they also are supposed to be remnants of the great outburst of matter from the Sun

The Fireballs that occasionally cross the sky in a brilliant streak of flame are detached fragments of comets that after long wanderings at length enter the Earth's atmosphere As they are rushing through the air at a speed of 20 or 30 miles a second, the friction makes them so hot, and expands the gas in them so much that they generally explode while still many miles high sometimes they are reduced to powder, but where the movement is less rapid, occasionally large lumps reach the ground

It has been objected to this theory that such a near approach of two suns would very seldom happen, the distance between them being so immense The answer is that suns with families of planets may, for all we know, be very rare we cannot hope for any increase of telescopic power that would show us the planets going round other suns

It is perhaps as well to emphasise that these theories do not at all imply that our System is a mere chance product of blind forces To imagine this would be just as unreasonable as it would have been for the man in the old anecdote who picked up a watch on the ground to conclude that that wonderful piece of mechanism had come together by chance But in those works of the Creator that we can study minutely, such as the growth of an oak tree or the formation of a coral island, we see that He works by slow processes of growth It is therefore agreeable to analogy to infer that the Solar System was formed by such processes, moreover, we can see similar processes actually in progress at the present day in various regions of the heavens

The seven planets of the ancients, which have been known from prehistoric times, included the Sun and Moon, Mars, Mercury, Jupiter, Venus, Saturn, and gave their names in this order to the days of the week, as we still see in the French names for these days The English names are taken from Saxon deities, Tiw, Odin, Thor, and Friga, the other three days can be immediately identified The discovery of Mercury is particularly creditable to the old observers, for even when we know where to look, it is always seen low down



DRAWING AN ELLIPSE

An ellipse is a foreshortened circle It can be drawn by putting two pins in paper, passing a loop of string over them, and passing a pencil round, keeping the string tight The two pins are the foci The Sun is in one focus of the planetary orbits

Earth over Boadicea's Statue. | Mars over Scotland House. | Jupiter over Turret of County Hall. | Saturn over Adelphi Terrace. | Uranus over St. Clement's Dane. | Neptune over St. Paul's Cathedral.

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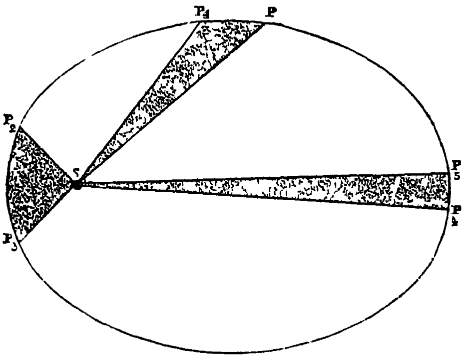

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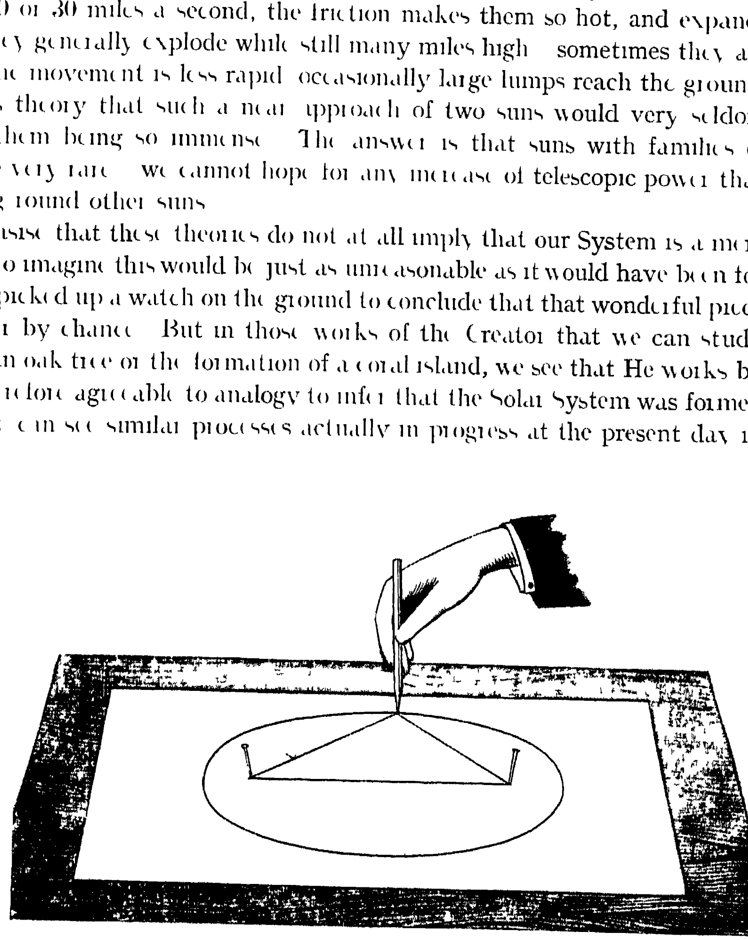

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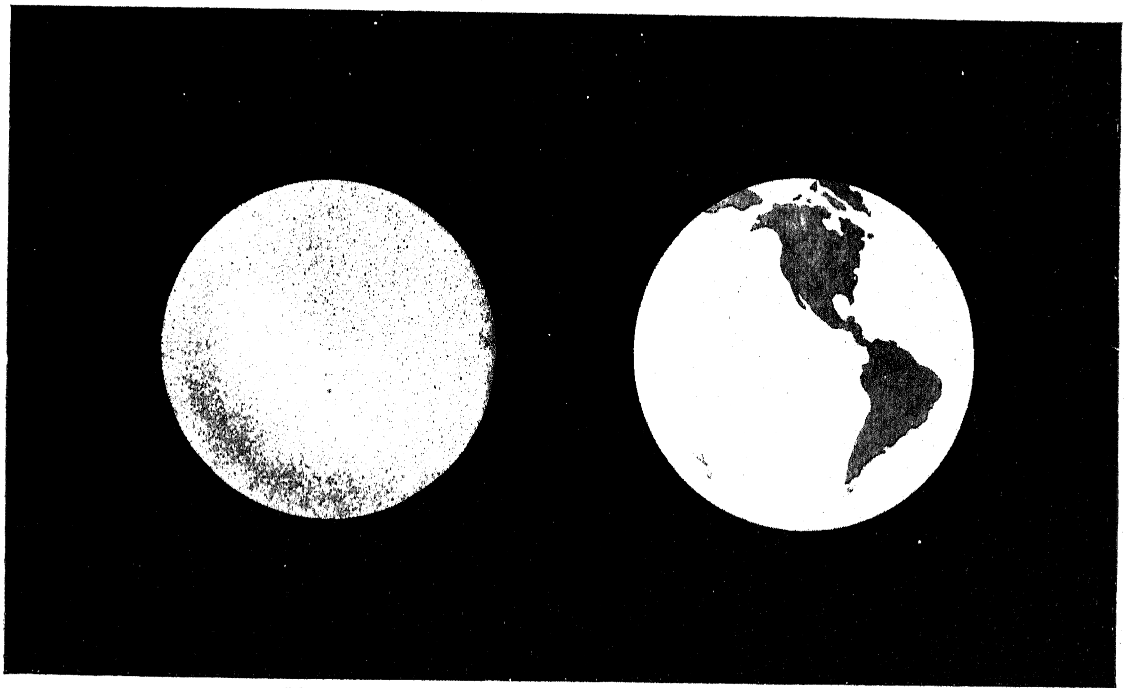
is due to the Earth overtaking them, its motion being more rapid than theirs. But the ancients looked on the Earth as immovable, and were driven to the view that the planets circled round a point which itself circled round the Earth. Other complexities were added to explain irregular movements—

"Centric and eccentric scribbled o'er,
Cycle and epicycle, orb in orb."

Much of this complexity was removed by the suggestion of Copernicus that the Sun, not the Earth, is the centre of the revolutions. A further step in advance was made by Kepler, who carefully studied the splendid series of observations made by Tycho Brahé, and announced the three laws of planetary motion. The first law stated that the planets move in ellipses, not in circles. Page 83 shows how an ellipse may be drawn by putting a loop of string over two pins fixed in paper, and passing a pencil round, keeping the loop tight. The two pins occupy the "foci," and the Sun is in one of the foci of the orbits. The ellipses in the case of the planets differ very little from circles, but in the case of the comets they are



COMPARATIVE SIZES OF VENUS AND THE EARTH.

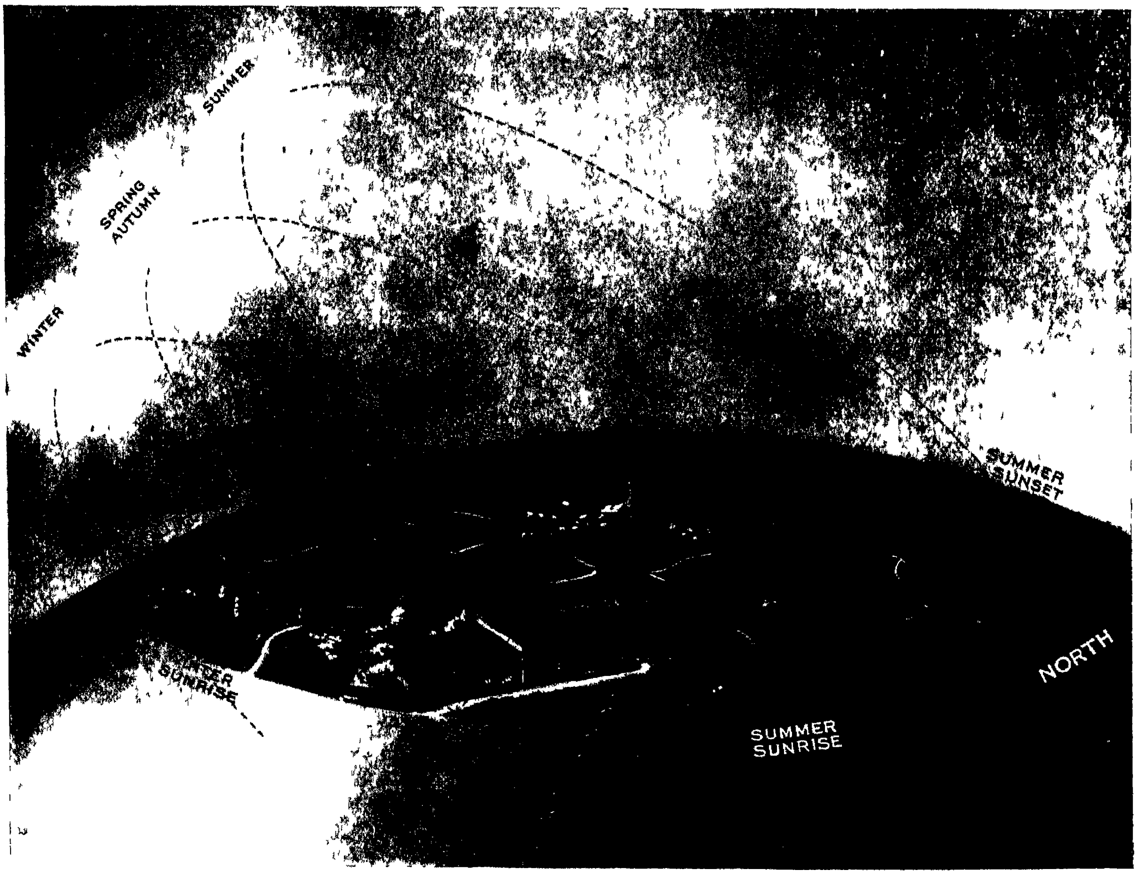
It will be seen from the picture that the two planets are almost exactly of the same size. The diameter of Venus is some 300 miles less, a trifling amount compared with 8,000. Venus is the only world resembling the Earth in size that we know of. Unfortunately it is a difficult planet to study, and we know little about it.

much more elongated. The second law gives the means of fixing the position of a planet in its orbit at any time. If we make a diagram of the path, as on page 83, marking its positions at daily intervals, then joining all these positions to the Sun, the triangles thus formed will all contain the same number of square miles or square inches on the diagram. This means that the nearer the planet goes to the Sun the quicker it moves, this extra speed being produced by the Sun's attraction. There is an easy way of representing the motion, which is very nearly exact. From the empty focus draw a set of lines all separated from each other by 10°, or some other selected angle; then the planet will be at the points marked by these lines at equal intervals of time, one-thirty-sixth of the whole period in the case given, *i.e.*, the angular motion about the empty focus is uniform. The third law was the one that gave Kepler the most trouble, but also the most satisfaction. It enabled him to find how long any planet would take to go round the Sun, being given its distance. (This is to be taken as the average distance, midway between the greatest and the least.) The unit in which the distance is to be measured is the Earth's

in the twilight, but it was very assiduously observed, and Fathers Epping and Strassmaier found it mentioned more often than any other planet in the Babylonian tablets, under the name of Guttu or Gud ud The early observers found the planetary motions very puzzling, for they were working on the false view that the Earth was the centre of the system The character of the apparent motion has been expressed accurately by Milton in the lines—

> " Their wandering course, now high, now low, then hid,
> Progressive, retrograde, and standing still "

Mercury and Venus were noted to swing, in pendulum fashion, from one side of the Sun to the other, being alternately morning and evening stars, the other three planets moved in a forward direction



APPARENT DAILY PATHS OF THE SUN

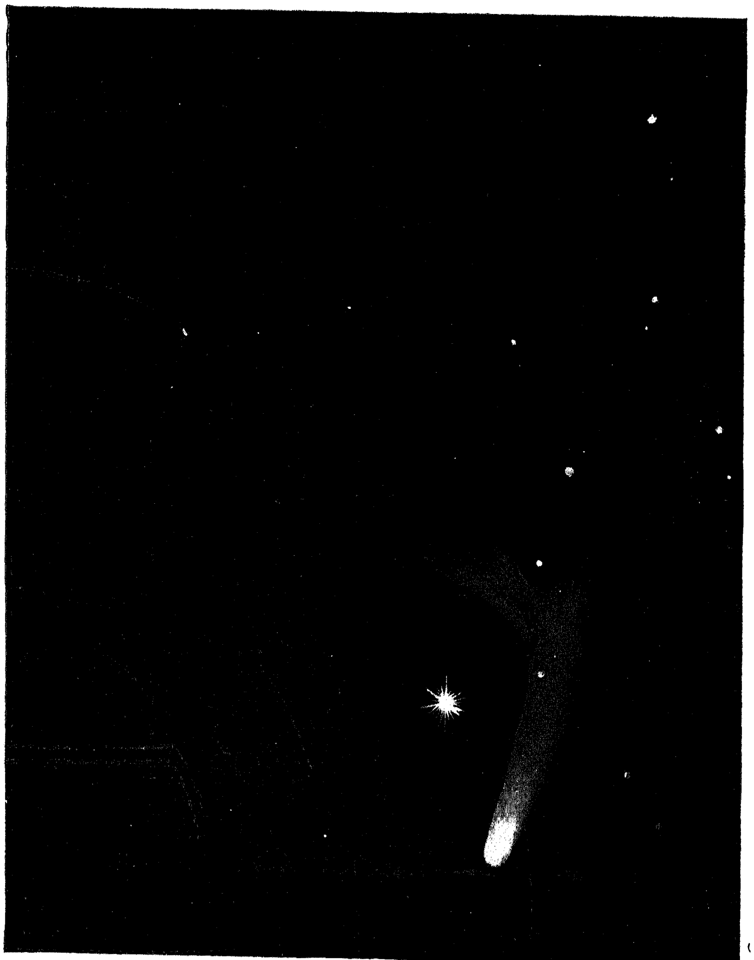
This picture shows that in summer the Sun rises in north-east, sets in north west, and is high up at noon In March and September it rises due east, sets due west, its noon height being moderate In winter it rises south east, sets south west, and is low even at noon It is above the horizon for 16 hours in summer, 12 at the equinoxes, 8 in winter

(that is, in the same direction as the motion of the Moon among the stars) for the greater part of the time, but it was noted that whenever they approached the position in which they were opposite to the Sun their forward motion slackened, then stopped, and for some weeks they retraced their steps, finally stopping again, and then resuming their forward march

The apparent paths of Mars and Neptune are shown on pages 89 and 90 Since Mars moves nearly as quickly as the Earth, it appears to move backwards for a short time only, on the other hand, Neptune, whose speed is only one-fifth of ours, moves backward for nearly six months, and its backward track is more than half as long as its forward one But we must remember that the backward movement is only apparent, and that each planet really moves forward continually the seeming backward motion

average distance from the Sun; we multiply this by its square root, and we have the time in years that the planet takes to go round the Sun. Thus, if the distance were nine times that of the Earth, the square root of nine is three, and 3 times 9 is 27, so the planet would go round in 27 years; this is nearly the case with Saturn. So if the distance were a quarter of the Earth's, the square root is one-half, the product is one-eighth: the planet would go round in one-eighth year, or 6½ weeks.

The fact of the Earth going round the Sun is brought home to us by the changing seasons. The Earth spins on an axis that is not quite upright to the level in which it goes round the Sun: in summer the northern end of the axis is towards the Sun; the regions near the North Pole then have daylight for the whole 24 hours (*see* Frontispiece, Midnight Sun). In our latitudes the Sun is visible for 16 hours of the 24 in summer, and rises very high in the sky; in winter it is visible for only eight hours, and remains low down. These changing tracks are shown on page 84. Mars, Saturn, and Neptune have their axes bent to about the same slope as ours, so have similar seasons; Uranus has a much higher slope, and very extreme seasons; Jupiter and the Moon have axes almost upright, and practically no seasons. We do not know how the axes of Venus and Mercury are placed.



From] [“*L'Astronomie.*”

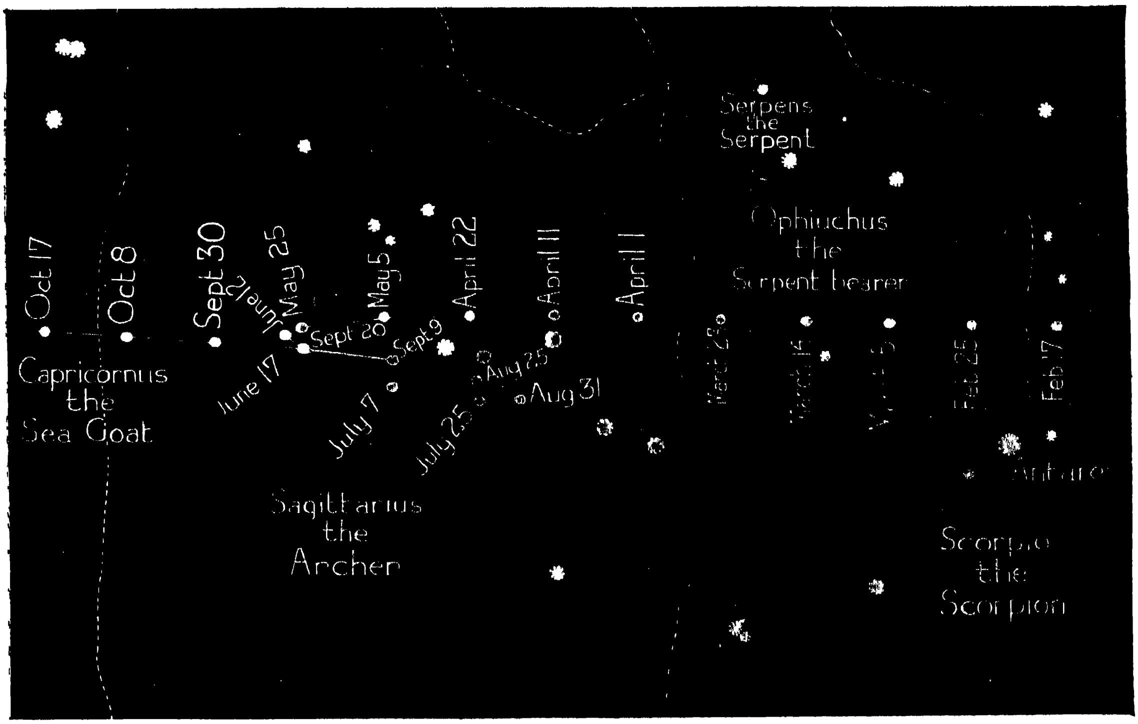
THE ZODIACAL LIGHT, VENUS, AND THE COMET OF JANUARY, 1910.

This beautiful picture was drawn by M. Ch. Sermasi, in Egypt. It shows Venus as a bright evening star, also the comet of January, 1910, with a curiously bent tail. The Zodiacal Light is the faint triangular patch of light. It is much better seen in the Tropics than in England. It is supposed to consist of clouds of fine dust travelling round the Sun: perhaps remnants of the dense streams of dust from which the planets are conjectured to have been built.

One result of the Earth not being in the centre of the planets' motion is that the distance from Earth to planet undergoes large changes. Venus, when nearest the Earth, appears very large, but a very thin crescent; as she recedes the disc gets smaller but more of it is lit up. On the whole it looks brightest when it is about half lit up; when furthest from the Earth it shows a fully-lit disc, but very small from its great distance.

The next great advance in our knowledge of the heavenly movements was made by Sir Isaac Newton. He proved that Kepler's laws indicated a great central attracting force in the Sun, which pulls all the planets to it, and prevents them from flying away in straight lines, which is the natural tendency of moving bodies unless some force acts upon them. He also proved that the force gets rapidly weaker as we go farther away from the attracting body. At twice the distance the force is one-quarter, at three

times the distance one-ninth, and so on This law of diminution is common to all actions, such as light and heat, that radiate outwards from a centre But Newton further showed that the mysterious force of attraction is present in all matter, and is the very same force that makes any object that we throw into the air come back to Earth This force also keeps the Moon circling round the Earth The fact that the force is universal adds immensely to the labours of astronomers, for not only does the Sun pull the planets but these all pull each other and make small changes in their paths round the Sun Some of these changes go on always in the same direction, others swing to and fro, like a pendulum The two points that are of most importance for the well-being of inhabitants, that is, the distance from the Sun, and the eccentricity or amount by which the Sun is out of the middle of the path, are not subject to large changes, so that if a planet is adapted for the support of inhabitants it will continue in that state for countless ages the action of the other planets may slightly modify the conditions, but will not alter them to a destructive degree One very important action of this kind is tidal action The Sun and Moon

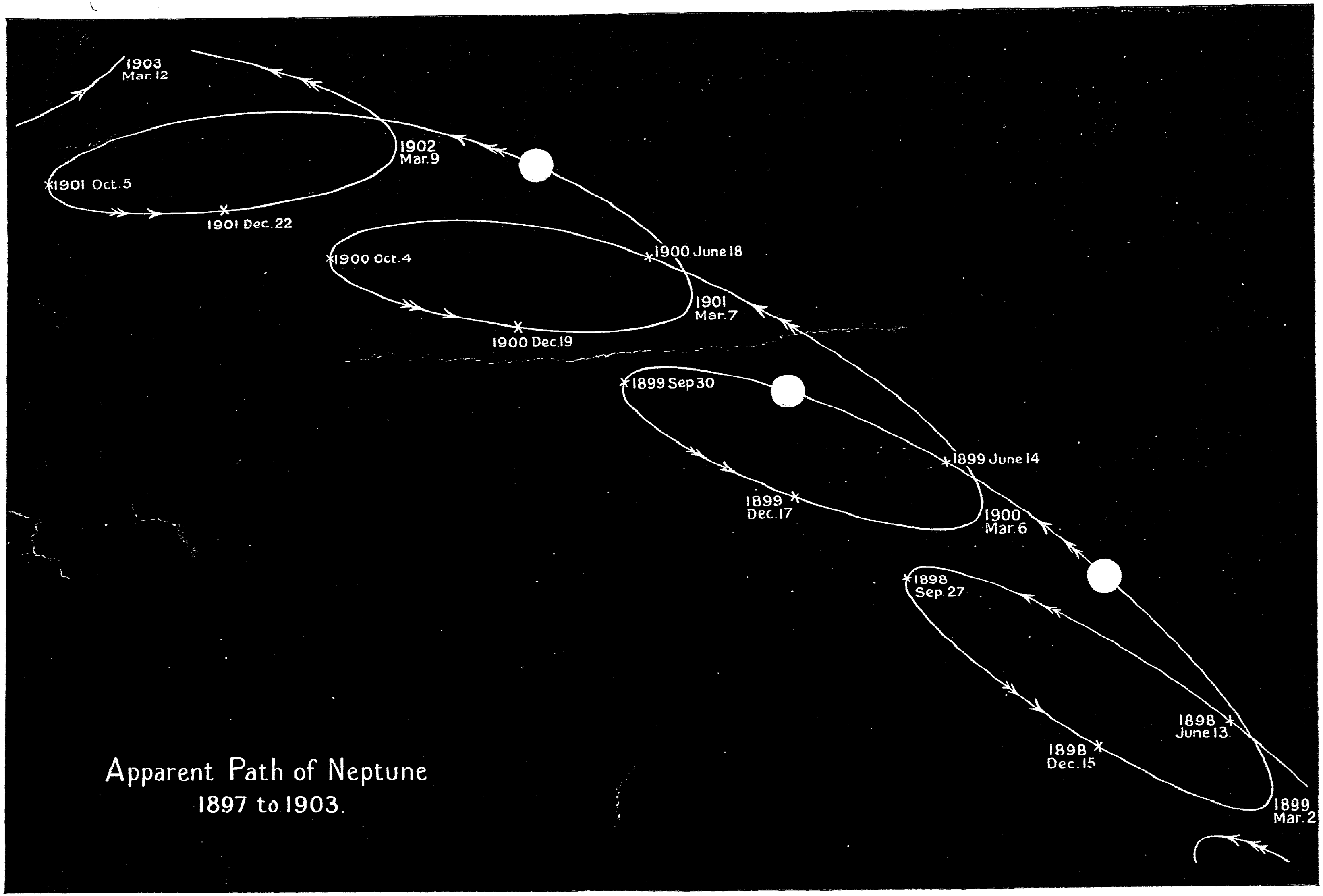


PATH OF MARS AMONG THE STARS IN 1907

This diagram shows the nature of the movement of an outer planet among the stars about the time of its " Opposition," or near approach to the Earth Mars moves forward from the Scorpion to the Archer up till mid June, then it halts, and moves back till the end of August, when it again halts, and then resumes its forward march, it is nearest to the Earth midway between the two halts

pull all portions of the Earth towards them, but they pull most strongly those portions that are nearest to them The result is a certain distortion of the Earth's surface, this takes place even in the solid ground but the mobile water of the oceans yields more readily, and so shows more tidal motion These tides act to a very small degree as a brake on the Earth's rotation, which is becoming slightly slower, as a result the Moon is very slowly increasing its distance from the Earth If the action were continued long enough, the Earth would at last always turn the same face to the Moon, as the Moon now does to the Earth This is doubtless the effect of the great tides that the Earth once raised in the Moon

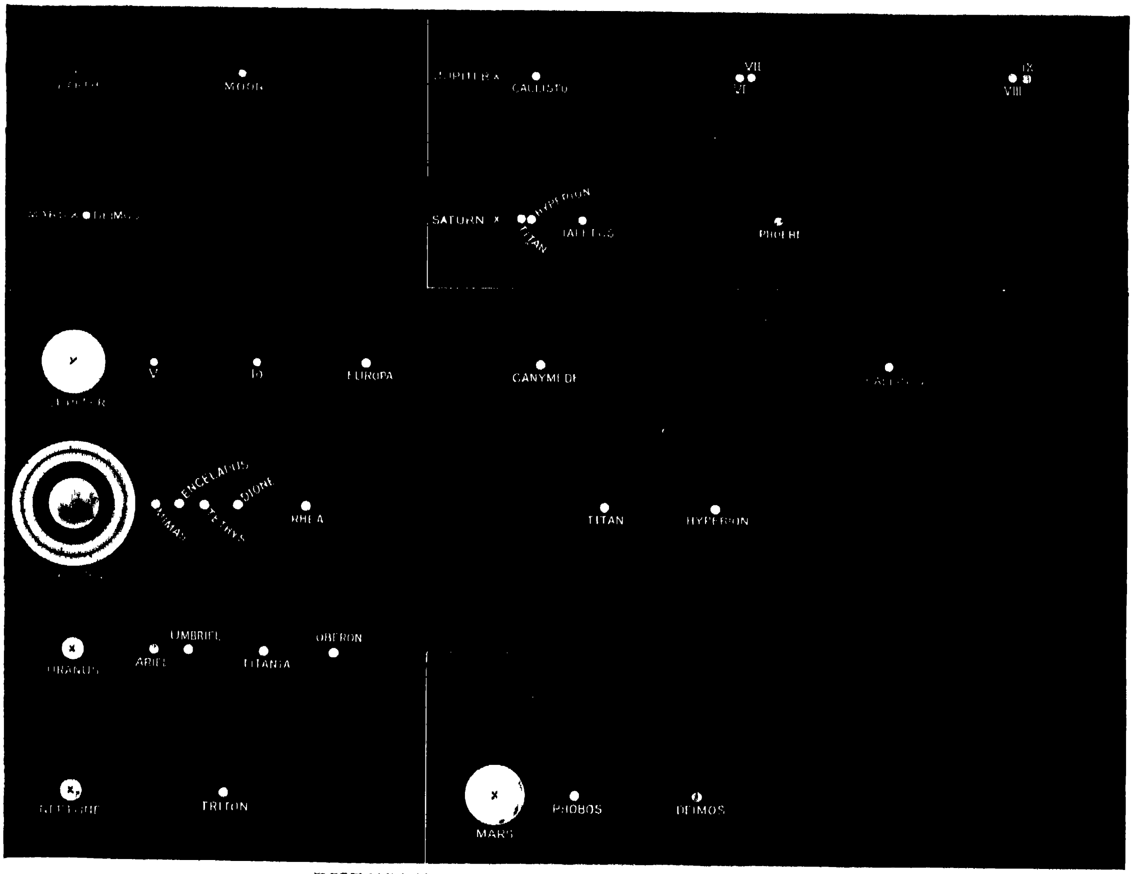
The Moon at times comes between the Earth and the Sun, and eclipses all or part of the Sun's light When all is cut off the eclipse is said to be total the view of totality is, however,



NEPTUNE'S PATH AMONG THE STARS.

Neptune has the slowest movement of any planet: as a consequence each backward movement is more than half as long as a forward movement. The X on the bottom of each loop shows the position of Neptune when in "Opposition" and best placed for observation. To avoid confusion the vertical scale has been made considerably greater than the horizontal one.

limited to a narrow tract of country, say 100 miles or less in width, but thousands of miles long These eclipses bring vividly before us the absence of air on the Moon, if any were present it would refract or bend the sunlight, so that the eclipse would not appear total These eclipses are of great value for studying the outer appendages of the Sun, notably the corona, a most beautiful halo of pearly light, which sometimes extends to upwards of a million miles from the Sun, but is wholly invisible except during totality Its extreme tenuity is shown by the fact that some comets have moved through millions of miles of corona at a speed of 300 miles per second, without the smallest perceptible loss of speed The corona may consist of streams of ions, or infinitesimal portions of matter, driven off from the Sun into space, and sometimes reaching the Earth When they do so they produce magnetic storms and cause displays of aurora, or "Northern Lights", this beautiful phenomenon is chiefly visible in the Polar regions, but comes much farther south at the time of



DISTANCES OF SATELLITES FROM PLANETS

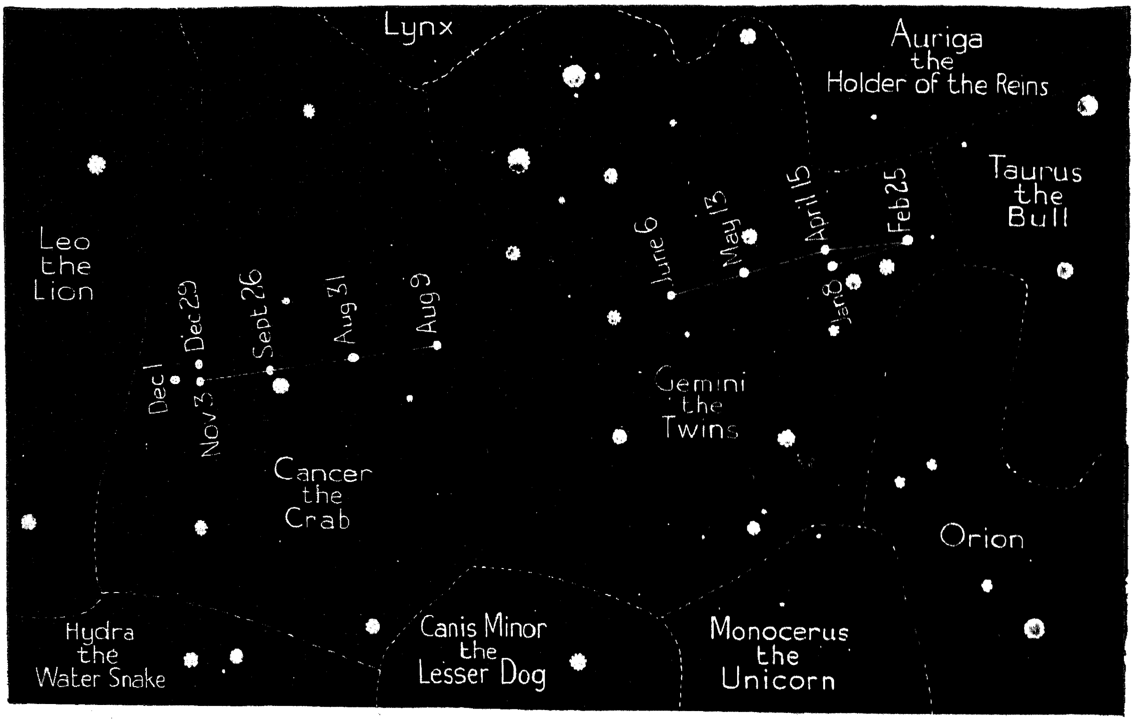
The Satellite distances are here shown on a uniform scale, except the very distant Satellites of Jupiter and Saturn, which are shown on the upper inset on $\frac{1}{20}$th of the scale of main diagram Phobos is at $\frac{2}{5}$ths of Deimos's distance from Mars, it is shown on lower inset on twenty times the scale of main diagram The dimensions of the globes of the large planets and of Saturn's ring are shown

magnetic storms It is supposed to be caused by certain rare gases, very high up in our atmosphere, which are made to glow by the discharge from the Sun Magnetic needles, such as compasses, are violently agitated during magnetic storms

Total eclipses of the Sun are common on the Earth as a whole, occurring every year or two, but they are rare at particular places There have been none in England for two centuries, but there will be one in the northern counties on June 29, 1927 All who can should take advantage of the opportunity, as there will be no other totality in England till 1999

There are many records of total eclipses in ancient history. They have served both to fix certain dates and to show that the Moon appears to move faster century by century: part of the seeming acceleration is really due to the Earth rotating more slowly, thus giving the Moon more time to move in a day, or a given number of days.

Eclipses of the Moon are more often visible at a given place than those of the Sun: they are due to the Moon entering the shadow of the Earth, and so ceasing to reflect direct sunlight. If the Earth had no atmosphere, the Moon would lose all light at such times, but the atmosphere has the power of bending light (just as a stick appears bent when inserted in water). Some of this bent light falls on the Moon, but it is reddened by passing through the thick layers of our air, just as the setting Sun looks red; the eclipsed Moon has generally a deep coppery hue, but some eclipses are darker than others, according to the degree of cloudiness of our air; the unusually dark eclipse of October 1884 was ascribed to the air being charged with dust from the great eruption of Krakatoa in 1883.

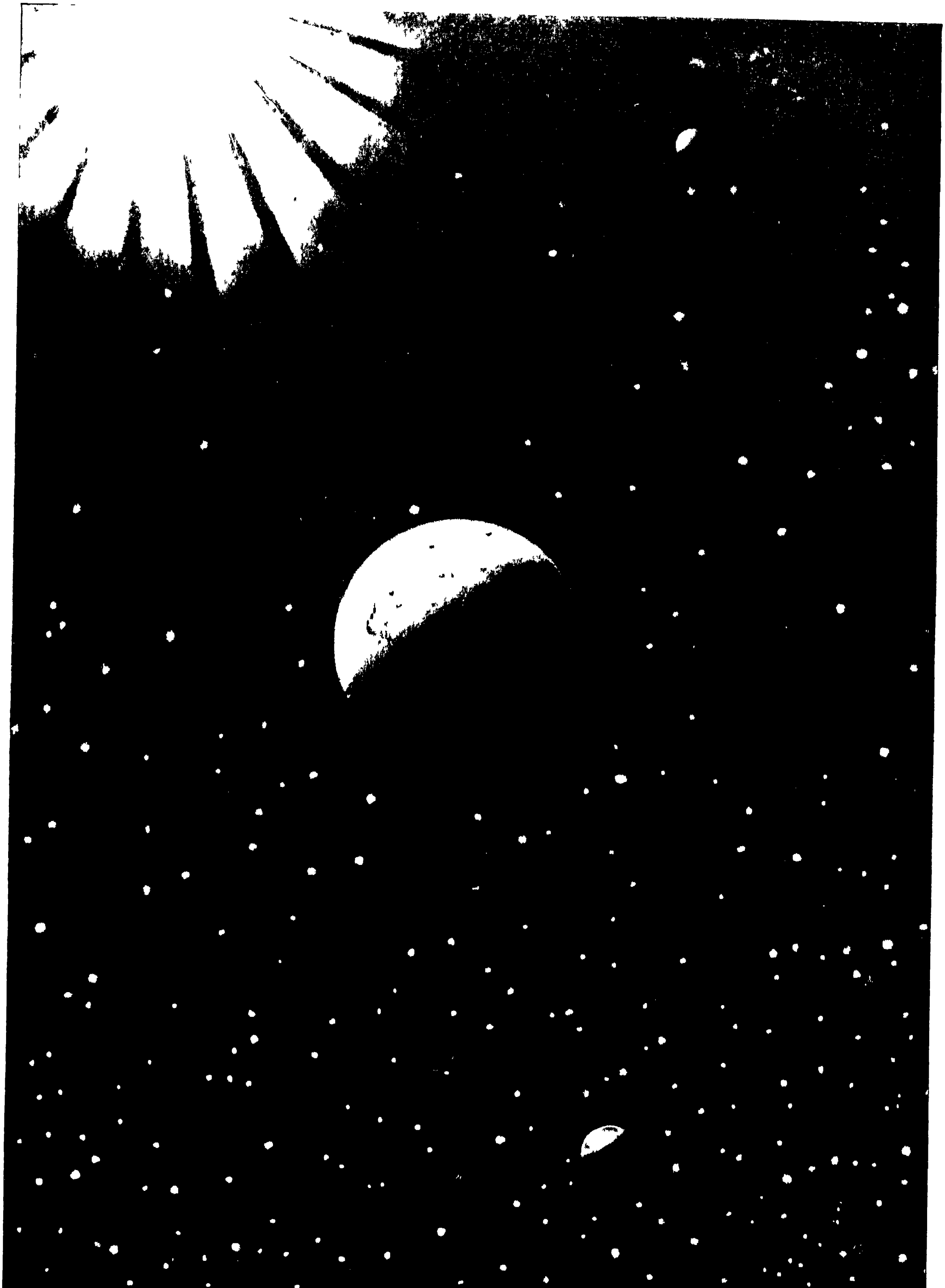


JUPITER'S PATH AMONG THE STARS.

Jupiter, like Mars, seems to move backwards among the stars when nearest to the Earth. It halted on February 25, and then went forward. Between June and August it was too near the Sun to be seen. It halted again on December 1. Jupiter advances about one constellation a year.

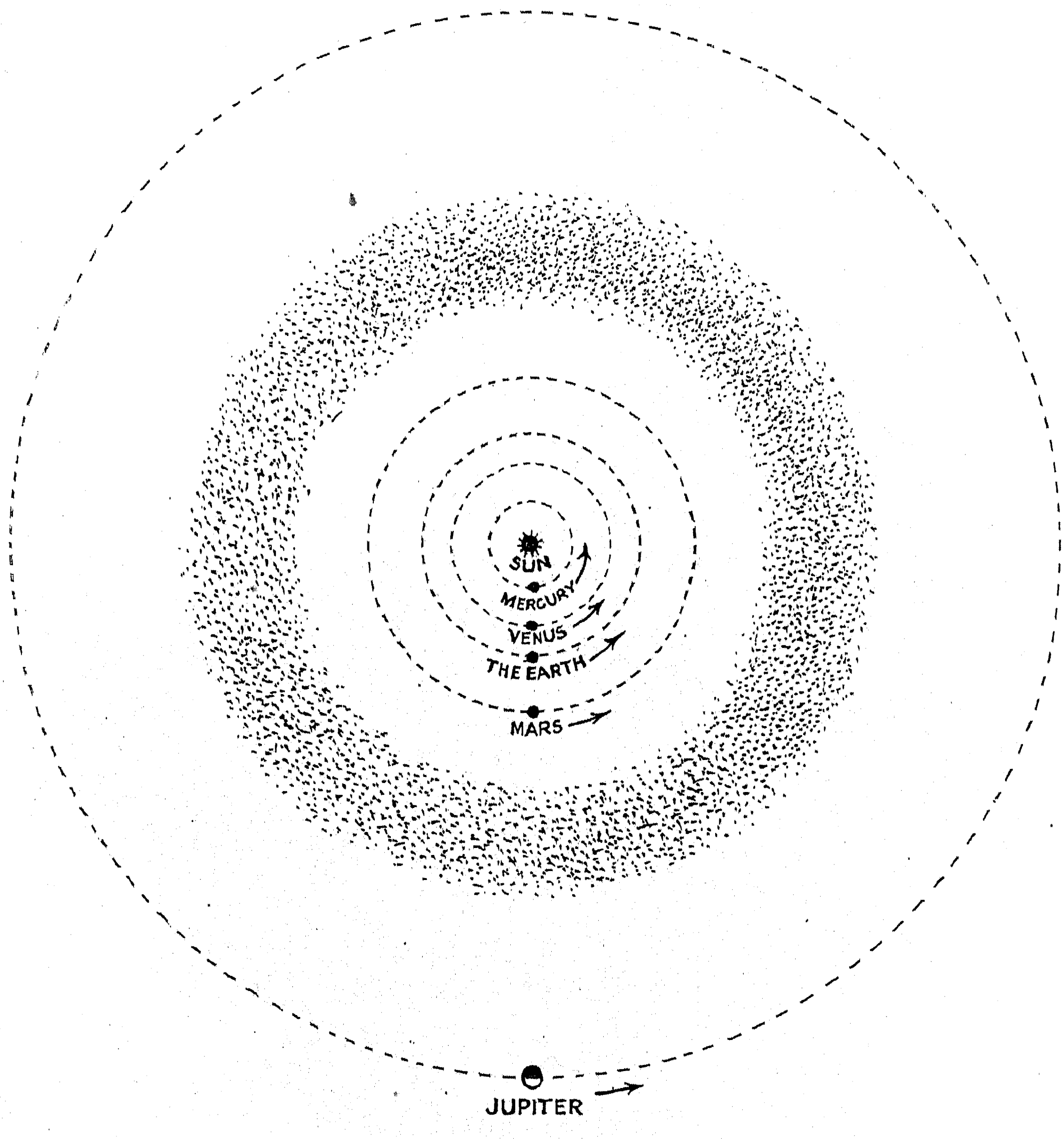
The moons of other planets also undergo eclipses in the shadows of their primaries. Eclipses of Jupiter's moons are frequent, and easy to observe with a small telescope. It was by means of them that it was first proved that light does not travel instantaneously, as the eclipses were seen earlier than was expected when Jupiter was nearest to the Earth, and later than expected when it was farthest away. The deduced time for light to come from the Sun to the Earth was $8\frac{1}{4}$ minutes: it takes four hours from the farthest planet Neptune, but four years from the nearest fixed star. The wireless messages that are now so familiar travel with the same speed as light, and go from France to Australia in one-twentieth of a second.

An occurrence of the same nature as a Solar eclipse is the crossing of the disc of the Sun by the planets Mercury and Venus, which are the only two that are nearer to the Sun than we are. Those of



THE EARTH AND MOON IN SPACE

This picture helps us to realise how the Earth and Moon hang freely in space without any support. It is important to remember that the downward direction in the Solar System is towards the Sun. The planets would fall into the Sun but for their rapid motion, which keeps them circling round it. Venus is also shown in the distance as a morning star.

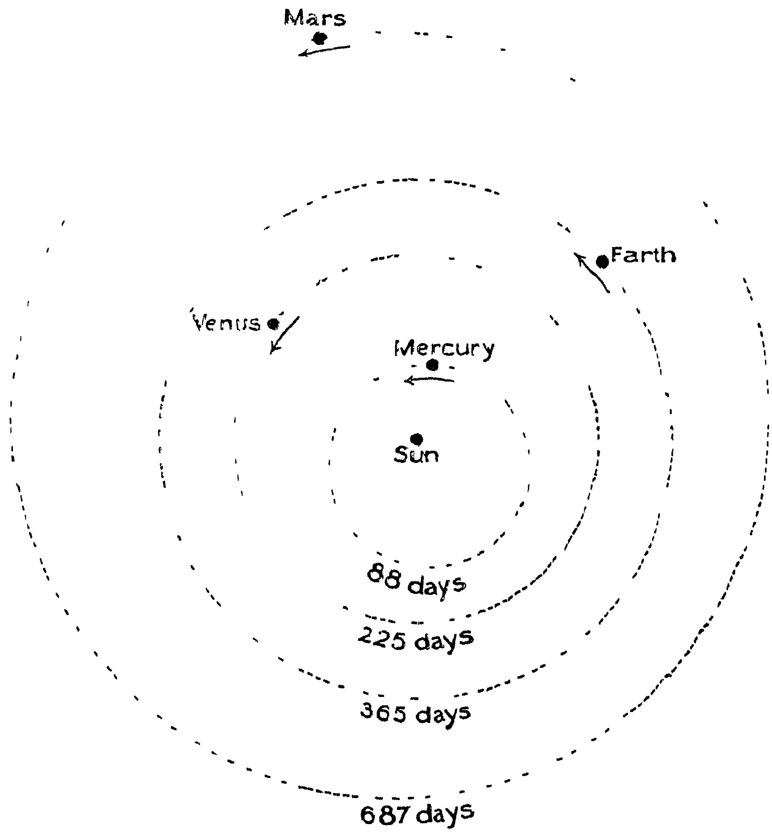


PATHS OF THE SMALL PLANETS BETWEEN MARS AND JUPITER.

Over a thousand of these tiny worlds are known, and there are doubtless thousands more. A few, like Eros, come inside the path of Mars, while others cross the path of Jupiter. Their paths are, in many cases, more oval and more tilted than those of the larger planets. They are also more highly inclined; the path of Pallas makes an angle of more than thirty degrees with that of the large planets. These peculiarities in the asteroid paths may be due to the great disturbances produced by Jupiter.

Mercury take place on the average at seven-year intervals, the next one being in May 1924 (The end of it is visible in England) It is well to impress on the reader that in observing anything on the Sun the eye must be carefully protected, either by a dark glass purchased at an optician's, or by a deeply smoked glass Using such a screen, Venus can be seen on the Sun without a telescope, but Mercury is too small to see without magnification Unfortunately, no present reader of these words can hope to see a transit of Venus, as the next will not occur till the year 2004 As thirteen revolutions of Venus are very nearly the same length as eight of the Earth, pairs of transits generally occur eight years apart, as in 1874 and 1882, and again in 2004 and 2012

Transits of Venus afforded the first method of obtaining the Sun's distance from the Earth It was necessary to send observers to a number of stations, widely scattered over the Earth's surface, who should each note the exact times at which Venus entered fully on the Sun and began to leave it One observer might see the entry as much as 25 minutes earlier than another who was thousands of miles away It is this difference of time that enables us to deduce the distance of Venus from the Earth Ever since the time of Kepler the proportionate sizes of the planetary orbits have been known so that if we find out the distance between any two planets it is a matter of simple multiplication to find all their distances Now Venus, when in transit over the Sun, is at her nearest to the Earth, which is the reason why these times were chosen as specially favourable for measuring her distance



THE PATHS OF THE FOUR INNER PLANETS

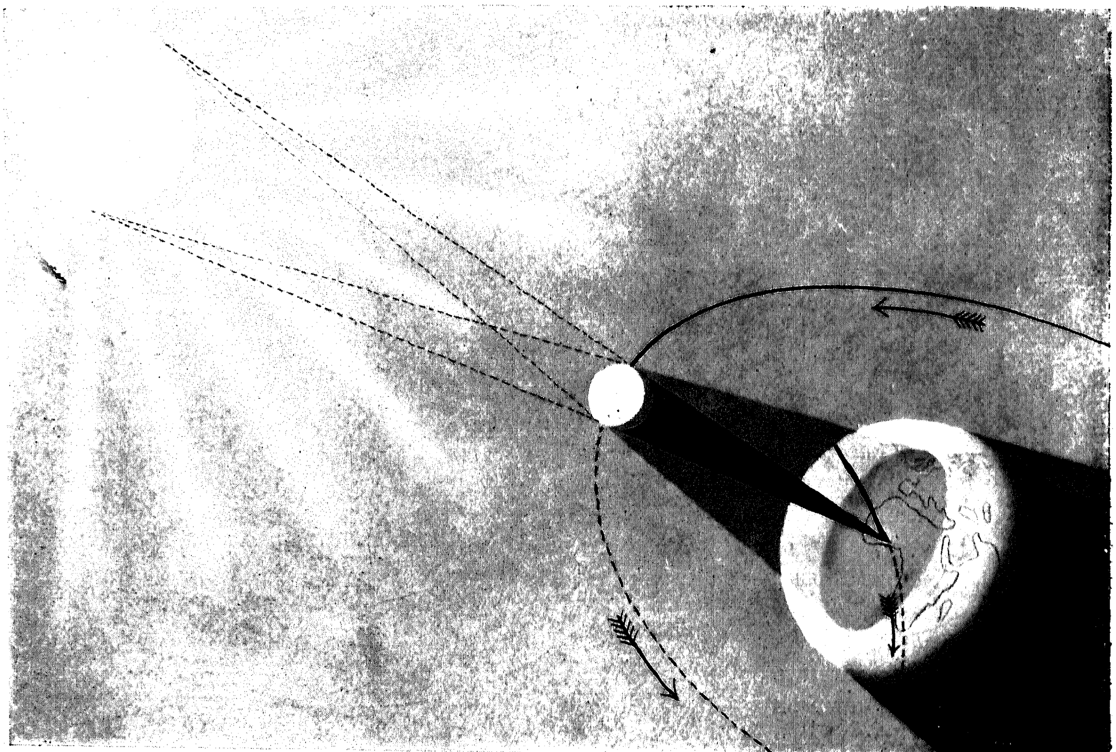
The paths of Mercury, Venus, Earth and Mars are shown, also the time that each takes to travel round the Sun The paths are all practically circles, but the Sun is considerably out of the centre of those of Mercury and Mars Mercury, when nearest to the Sun, is only $\frac{2}{3}$ of its farthest distance it receives more than twice the light and heat in the former case than it does in the latter

The ancient astronomers had a fairly accurate knowledge of the Moon's distance (about a quarter of a million miles), but they failed utterly in their attempts to measure the Sun's distance They thought that it was 19 times the distance of the Moon, or 4½ million miles, an estimate that we now know to be only one-twentieth of its real distance, but the false estimate held the field for 2,000 years, and it was not till many years after the invention of the telescope that serious efforts were made to correct the estimate The problem is by no means an easy one, and the true value was only reached by many steps Halley appears to have been the first to perceive the utility of transits of Venus, at his suggestion elaborate arrangements were made for observing the two transits of 1761 and 1769 The observations gave 95 million miles as the Sun's distance This was quite a good approximation, though the value now accepted is more than two million miles less It is

important to note that the distance itself has not changed, for in that case the year would also have changed in length.

The transits of 1874 and 1882 still left considerable uncertainty, as it was found to be unexpectedly difficult to fix the instant when Venus just touched the edge of the Sun. Venus is surrounded by an extensive atmosphere, which bends the Sun's light, and causes a bright ring to be seen round the part of the planet that has not yet entered. Owing to this ring there is no moment at which the two edges appear to be in contact.

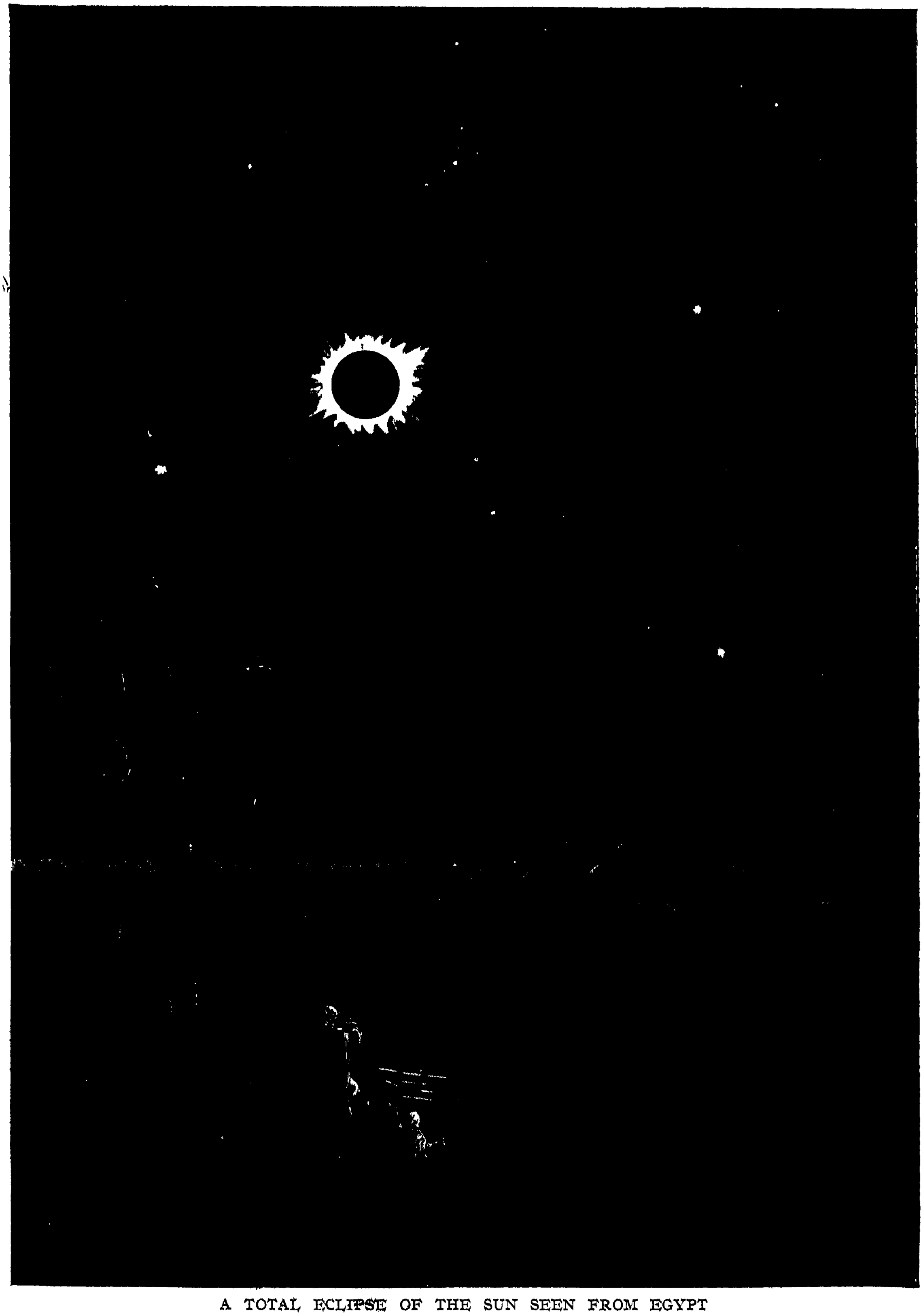
Fortunately, the discovery of the little planet Eros, which approaches the Earth within 15 million miles, affords a much better method than transits of Venus for finding the Sun's distance ; it made a fairly close approach to the Earth in 1900, and will make a still closer one in 1931. The value now accepted for the Sun's distance (*i.e.*, the average between the greatest and the least distances) is 92,900,000 miles. This is unlikely to be changed in the future by much more than 100,000 miles, or



MOON'S SHADOW ON THE EARTH IN A TOTAL ECLIPSE OF THE SUN.
All the heavenly bodies that are not self-luminous throw long tapering shadows. When that of the Moon falls on the Earth, as it does every two years or thereabouts, it traverses a long narrow tract of country, or sea. All people inside this track see the Sun entirely covered, and are able to observe the corona.

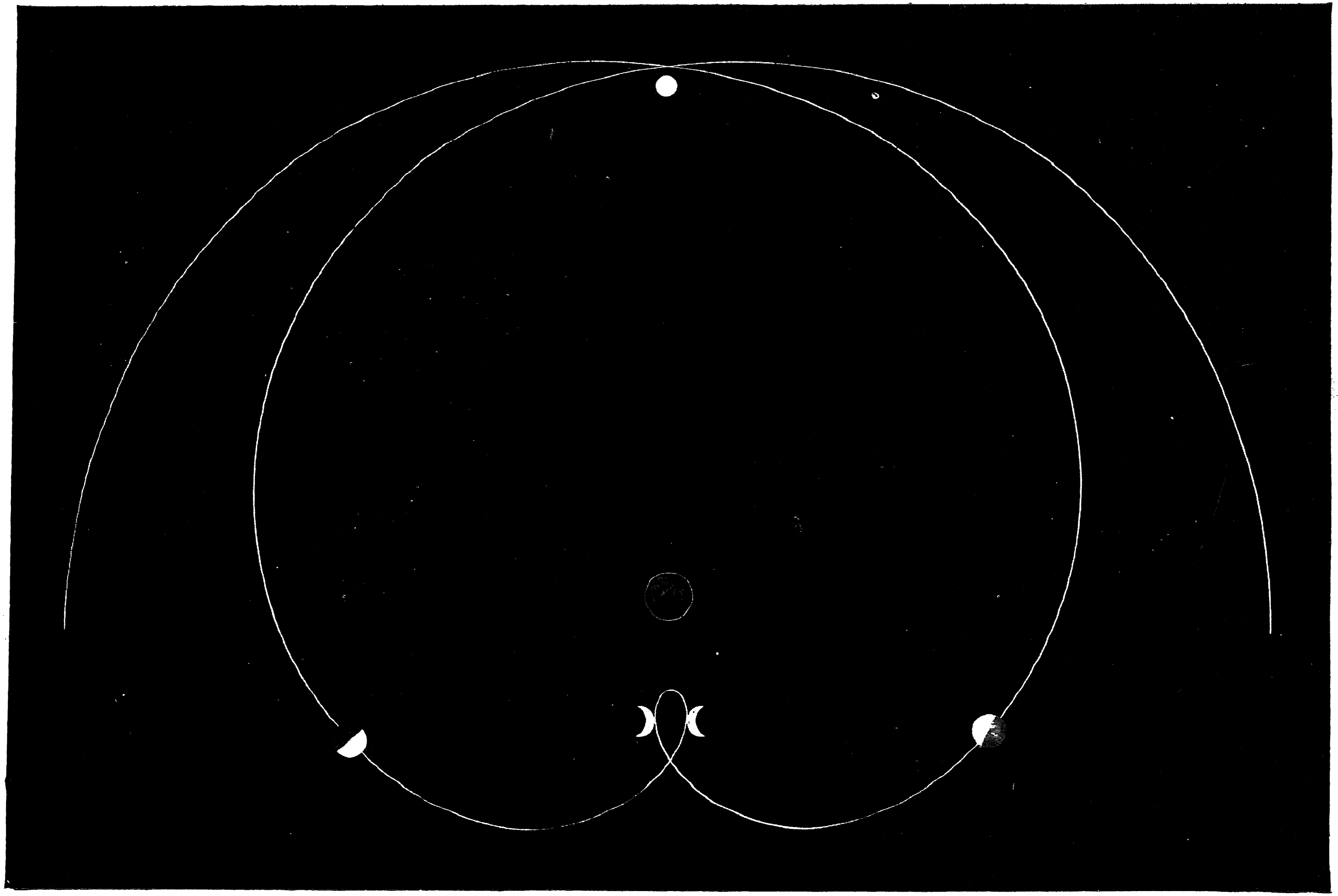
one-thousandth of the whole distance. The reason that such pains are taken to improve our knowledge of the distance is that it is the astronomer's " Yard Measure," to which all other distances are referred. It may be taken as certain that transits of Venus will not be used again for this purpose, though they will doubtless always be observed for the solution of other problems.

Though the planets all go round the Sun in the same direction, this is not true of their rotation on their axes ; the two outer planets spin round their axes in the reverse direction to the rest. Now it has been noticed that if the theories of planetary development from streams of particles are true, the particles on their inner sides would be moving more quickly round the Sun than those on the outside ; this would make the planet spin backwards. Hence it is conjectured that all the planets originally rotated backwards. If a gyroscope is set spinning, and



A TOTAL ECLIPSE OF THE SUN SEEN FROM EGYPT

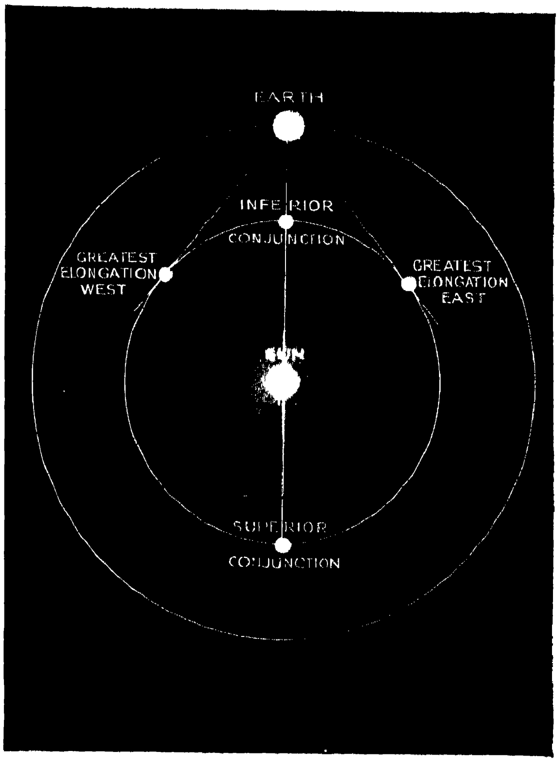
In a total eclipse of the Sun the light quickly changes from daylight to a deep gloom almost like night The Moon, whose dark side is towards us, appears of an intense black, round it the corona is seen as a beautiful pearly radiance Bright jets of red flame (the prominences) are often seen Many stars also become visible



THE SHAPE OF THE PATH OF VENUS AS SEEN FROM THE EARTH.

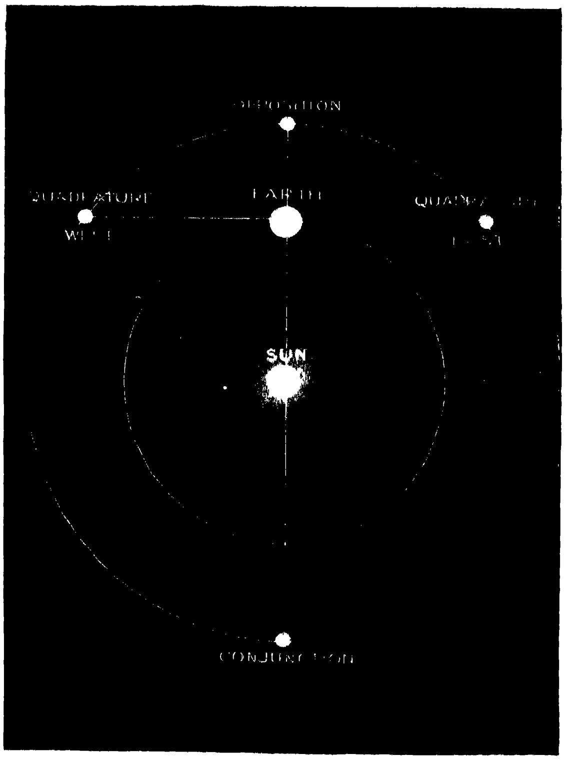
This picture conveys the same information as the one on page 80, but in a different form. The orb inside the curve is the Earth, and the curve illustrates the complicated result of the two circling motions, that of Venus and that of the Earth. Venus when farthest from us is at six times its distance when nearest; it takes 9½ months for it to pass from the farthest point to the nearest. The little loop in the curve where it is nearest the Earth illustrates the fact that at such times Venus appears to us to move backwards, since it is overtaking the Earth and leaving it behind. The little crescents and discs placed beside the curve show approximately the changing appearance of Venus.

then carried round in a circle in the opposite direction to its spin, after the axis which supports it has been clamped, it is found that it turns over, so as to make the two motions in the same direction It is supposed that the tidal action of the Sun has in this manner turned the planets over, with the exception of the two outer ones, for which the tidal action is very weak Uranus has, however, turned nearly half over, so that its axis is almost in the plane of its orbit, while Neptune has hardly turned over at all The outermost satellites of Jupiter and Saturn go round these planets in the backwards direction, some have therefore conjectured that they date back to the early days when those planets rotated backwards But it may also mean that these satellites are later additions to Jupiter's family through capture Capture of one body by another is not such a simple matter as is sometimes imagined In fact, it cannot take place without the aid of a resisting medium—that is, an extensive region



ORBITS OF THE EARTH AND AN INFERIOR PLANET

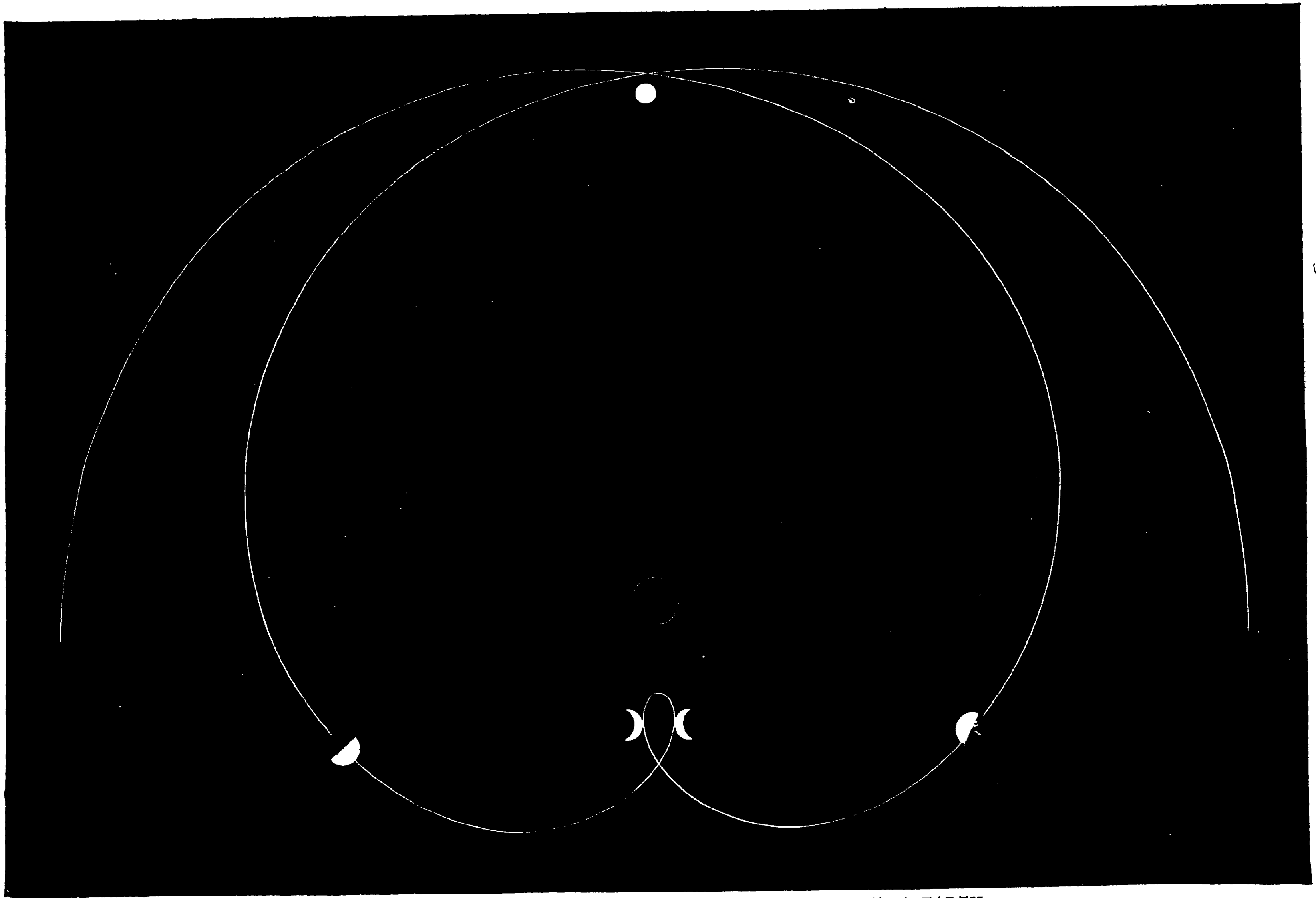
This picture applies to the planets Mercury and Venus They are nearest to the Earth when in a line between it and the Sun, they then turn their dark side to us, and are invisible except when they pass across the face of the Sun They are best seen when in Elongation East (evening) or West (morning)



ORBITS OF THE EARTH AND A SUPERIOR PLANET

All the planets outside the Earth are best placed for observation when in "Opposition" or exactly opposite the Sun They are said to be in "Quadrature" when their direction is at right angles to that of the Sun When in or near conjunction they cannot be seen

round the larger body filled with gas or scattered dust which retards the motion of the other body and thus brings it under the control of the large one There is certainly no medium of the requisite density nowadays in any part of the Solar System, but if the planetesimal hypothesis is true, there must have been abundance of it in the early days of the system, and it probably required a long time for it to be wholly absorbed in other bodies We note that the asteroids approach close to Jupiter's orbit, and many of them are as large as these outer satellites, which are not more than 100 miles in diameter The suggestion that the satellites are captured asteroids is therefore reasonable It should be noted that their retrograde motion round Jupiter does not mean that their motion round the Sun before capture was retrograde The speed of their motion round Jupiter is much less than Jupiter's speed round the Sun, so



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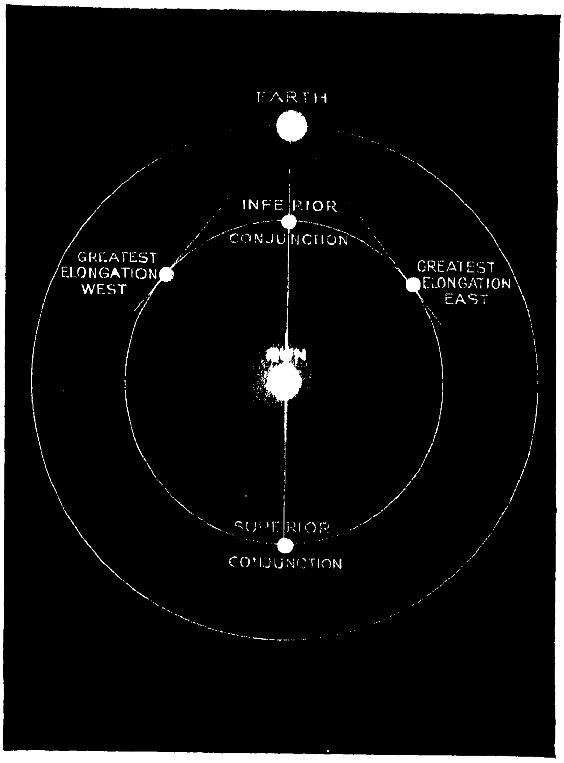

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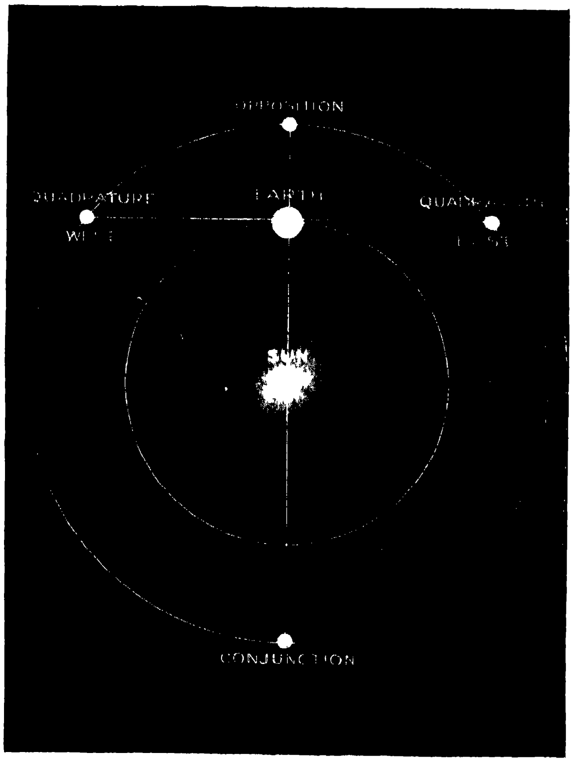

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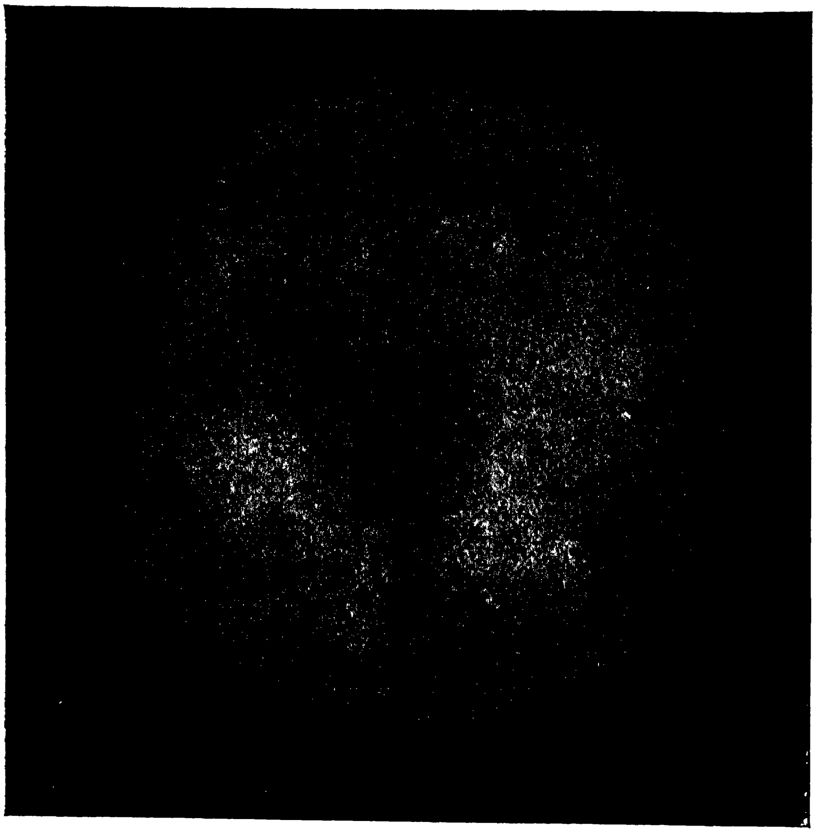
that if they escaped from Jupiter they would go round the Sun forward, not backward It has, in fact, been shown mathematically that it is easier for bodies to be captured as retrograde satellites than as direct ones

The origin of the large inner satellites of the giant planets is not likely to have been by capture Both their sizes and their paths are related to each other in a manner that makes it likely that they are true members of a common family, not mere vagrants swept in from outside

Reference should be made here to the illustration on page 3 of the conjectured birth of the Moon The theory there illustrated was worked out by Sir George Darwin He supposed the Earth to have rotated originally in four or five hours, and that tides raised by the Sun caused it to become first egg-shaped, then pear-shaped, and finally to break into two very unequal parts, the smaller of which became the Moon, each body would cause tides on the other Those by the Earth on the Moon slowed down its spin till it perpetually turned one face to the Earth, as it still does to-day The tides on the Earth are supposed to have lengthened its day from five hours to 24, with a corresponding increase in the Moon's distance The process is still going on, though very slowly

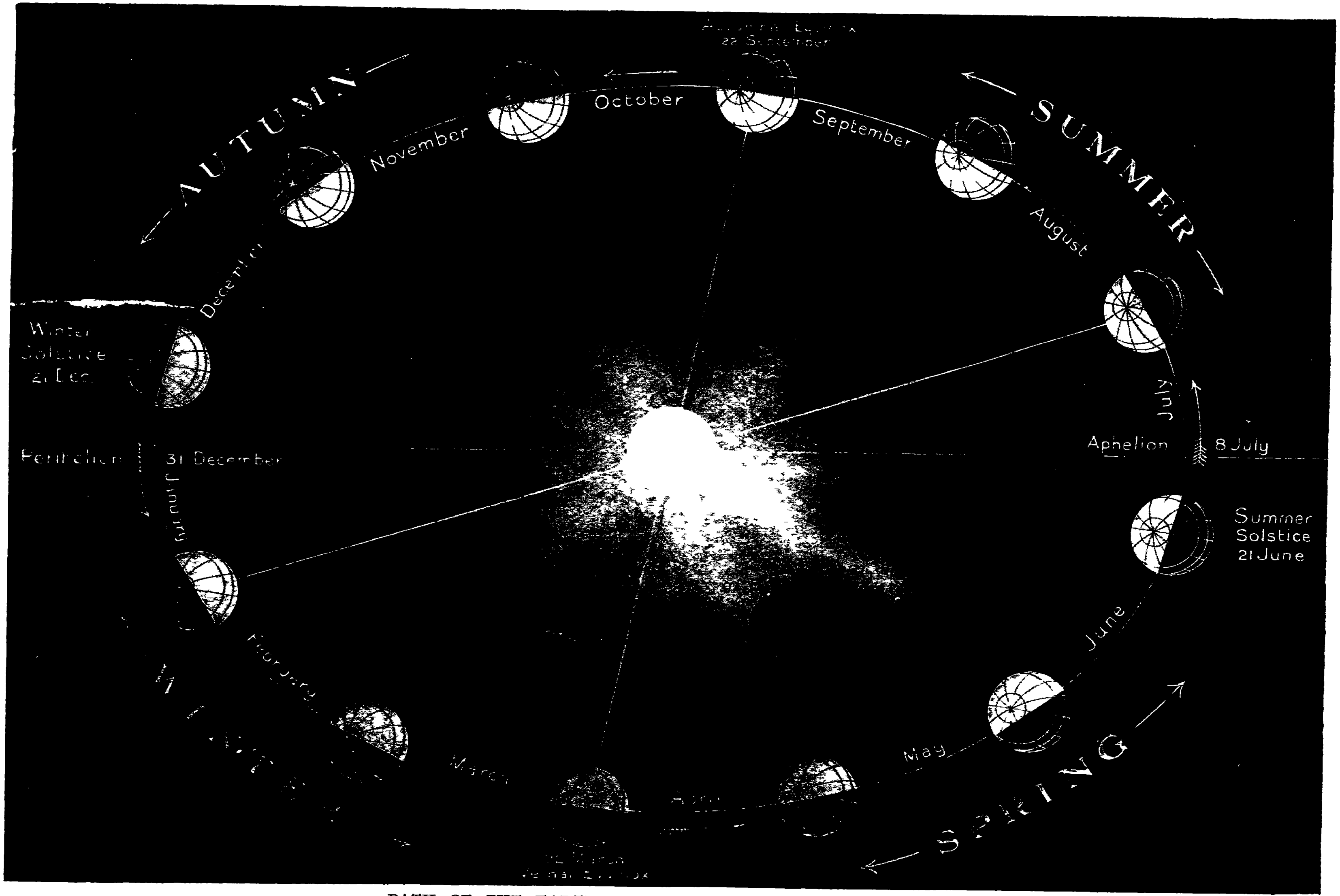


TRANSIT OF VENUS

A transit of Venus is very rare, the next two will be in 2004 and 2012 The planet can be seen without a telescope (but using a dark glass) as a round black spot, which passes in a few hours across the Sun Transits have been used to find the Sun's distance

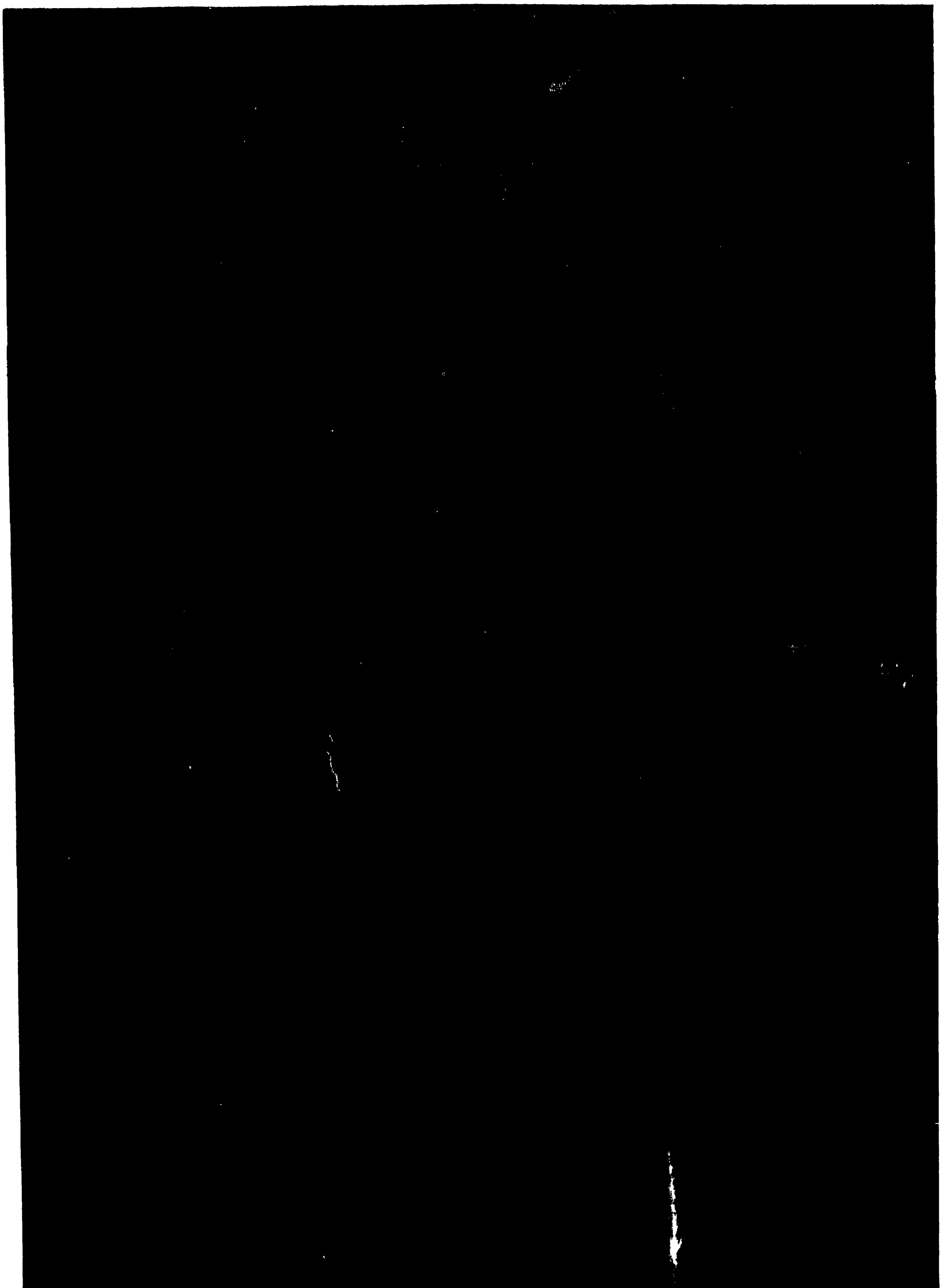
Sir G Darwin examined whether the same theory would account for other satellites but the answer seems to be in the negative All the other satellites are very much more insignificant in size, compared with their primaries, than the Moon is compared with the Earth, also the tidal action of the Sun on the exterior planets is hardly strong enough to have caused a disruption While we know nothing for certain in the matter, we may conjecture that when the giant planets were still dust-clouds, small subordinate nuclei arose in them, in addition to the main central one

A study of the planes or levels in which the satellites travel round their primaries is instructive All satellites that are very close to their primaries travel in the plane of the planet's equator, or very close to it This is the case with the two tiny satellites of Mars, with the five inner satellites of Jupiter, and the seven inner ones of Saturn The four satellites of Uranus all move in the plane of its equator, this is known to be the case, for otherwise the equatorial bulge of the planet would cause their planes to shift, a process that is actually going on in the case of Neptune's satellite and that enables us to say approximately how Neptune's equator is situated Our Moon and the two outer satellites of Saturn



PATH OF THE EARTH ROUND THE SUN THE SEASONS

The Earth spins on an axis which is inclined to the level in which it moves round the Sun In winter the northern hemisphere is turned away from the Sun, and the North Pole has 6 months night At the equinoxes the Sun is on the horizon at the poles and all places have 12 hours day and 12 hours night In summer the North Pole has perpetual day, and northern regions enjoy a long day and a high Sun at noon The Earth is in perihelion (nearest Sun) early in January, farthest in early July (aphelion) The former distance is 91½ million miles, the latter 94½ million miles This cause makes the northern winters milder than they would otherwise be



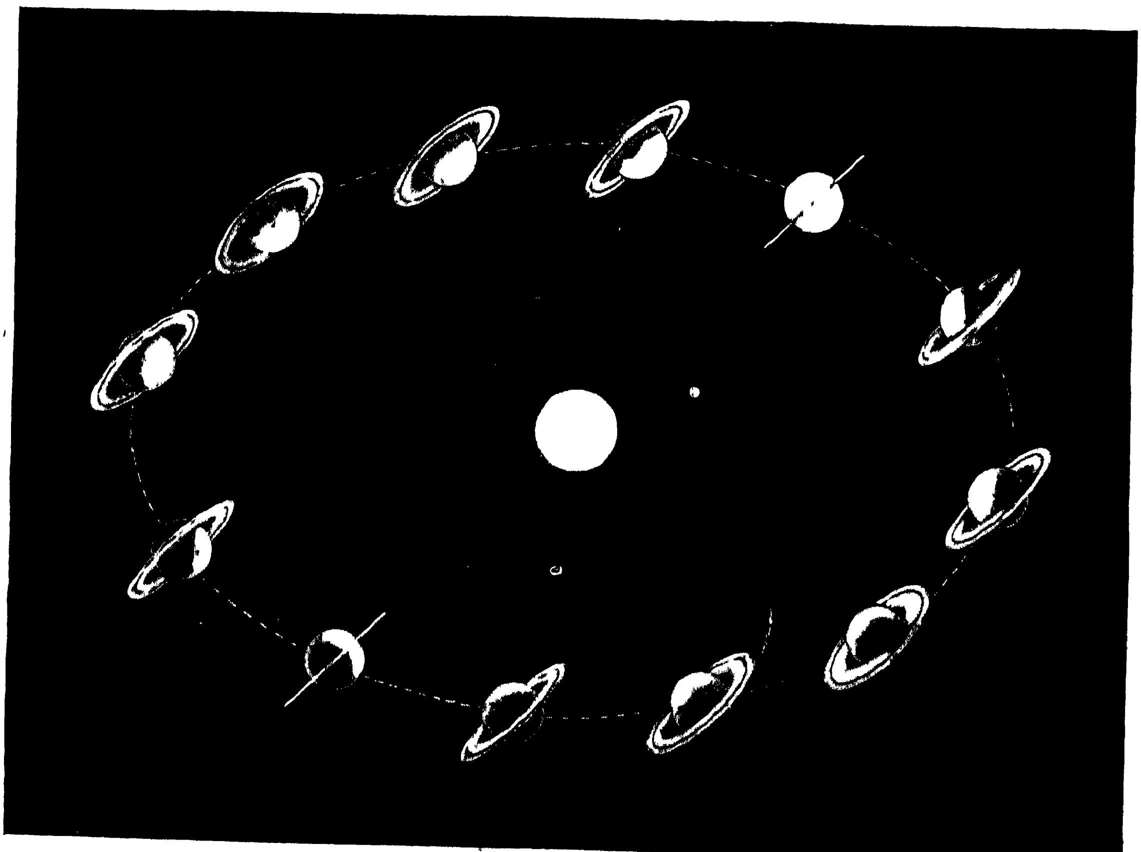
[By Max Raebel

THE AURORA BOREALIS

It has been seen (page 27) that the Sun at times sends out streams of electrified particles When these reach the Earth they cause a magnetic storm, and also cause displays of Aurora Borealis, which are due to the glowing of certain rare gases very high up in the atmosphere They often assume very beautiful shapes, and change rapidly in appearance They are commonest in high latitudes, but in intense magnetic storms they are seen much farther south There is an 11 year period in aurora, corresponding to that in sunspots

move in nearly the same plane as that in which the primary goes round the Sun. On the other hand, the four outer satellites of Jupiter, which are all very tiny bodies about 100 miles in diameter, move in planes that are highly inclined both to Jupiter's equator and to his orbit; this is a further argument in favour of their being captured bodies.

I have said that the Moon's case is unique. I am following Sir G. Darwin in this, but I add on my own account that there is the possibility of a second example being present in the Solar System, though the matter is extremely speculative. The suggestion is that Mercury may originally have been a satellite of Venus that has subsequently escaped from it and become a separate planet. The idea occurred independently to two people—Mr. George Craig, of Glasgow, and Dr. Harold Jeffreys. The latter dismissed

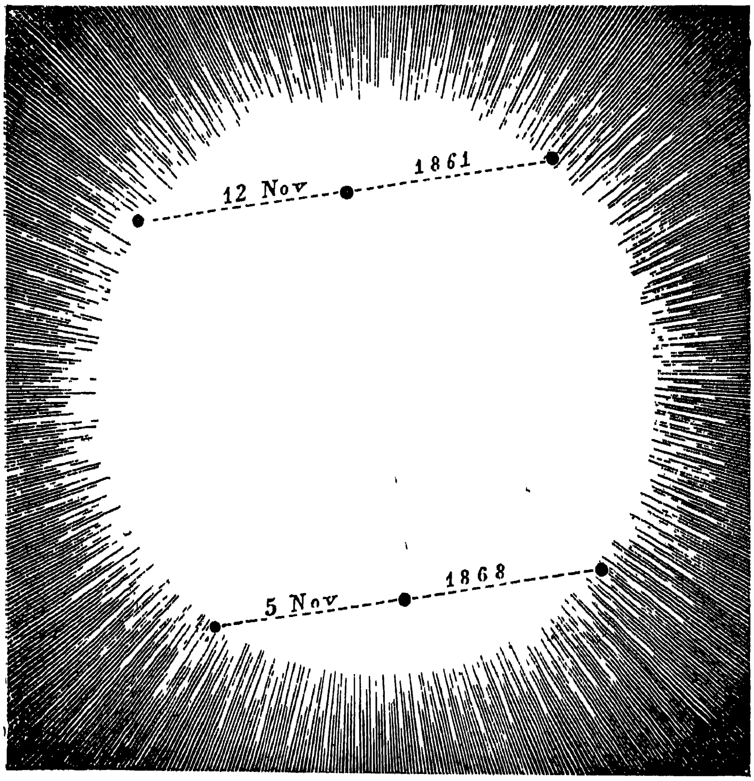


PHASES OF SATURN'S RING.

Saturn, like the Earth, spins on an axis inclined to the level in which it goes round the Sun. For half its period of 29½ years the Sun shines on the north pole of the planet, and on the northern face of the ring; for the other half on the southern face. At the equinoxes of Saturn the ring is turned edgewise.

the idea after consideration, but his grounds for doing so do not seem to me to be quite convincing. While it is impossible that the idea should ever become more than a wild guess, it does seem to explain a good many points that are otherwise puzzling. In the first place Venus and the Earth are so alike in size, and such near neighbours, that we should expect them to begin their career with something like the same rotational speed. But if solar tides tended to produce disruption on the Earth, they would do so still more on Venus, since there they would be two and a half times as strong. There would thus be nothing surprising in a larger piece breaking off, and in fact we find that Mercury is three times as heavy as the Moon. The presence of this great satellite would of course raise high tides on Venus, which, in addition to the strong solar ones, would rapidly check its rotation. Now the latest results of the spectroscope applied to Venus suggest that its time of spin is not less than a fortnight. Mercury

would have its rotation checked still more rapidly, and the reaction of its tides on Venus would cause it to recede from it much quicker than the Moon did from the Earth. Now there would be a limit of recession, beyond which the satellite would cease to be subject to its primary, and might become an independent planet. This limit would be reached sooner with Venus than with the Earth, owing to its greater nearness to the Sun. Supposing that Mercury "escaped" when it was at "New Moon," its subsequent orbit would be an ellipse, distinctly smaller than the orbit of Venus. To explain how it got into its present orbit it is necessary to imagine a considerable amount of resisting medium, which would act more effectively on Mercury than on Venus, since the former has less than one-twentieth as much matter in it as the latter, and also has its materials less tightly packed. As the Zodiacal Light extends beyond the orbit of Venus, it is evident that even to-day there is a measurable amount of resisting medium present; it is quite probable that this was denser in the early days of the Solar System.

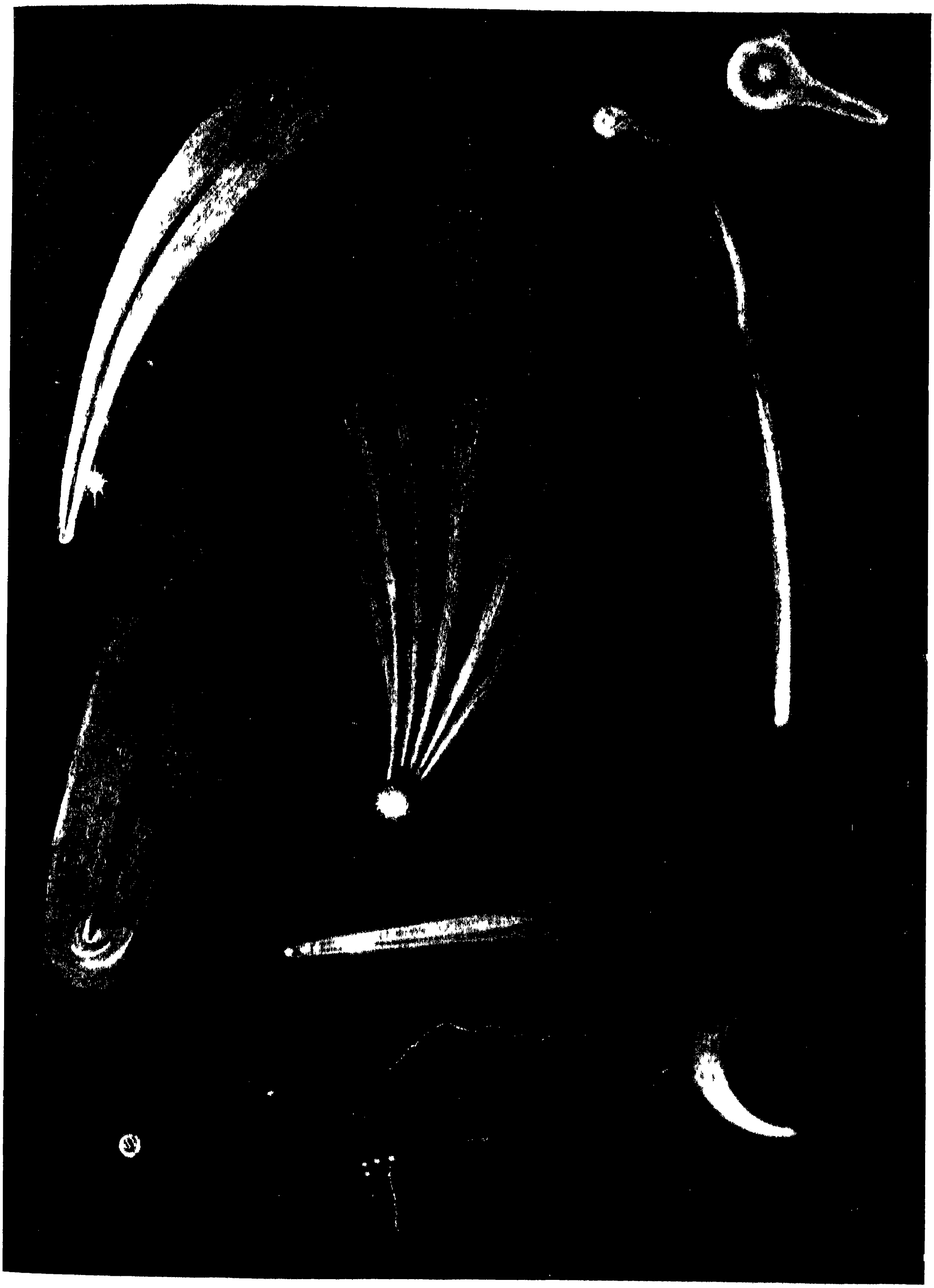


TRANSIT OF MERCURY

Mercury transits the Sun every seven years (on the average). It is too small to be seen on the Sun without a telescope; unlike Venus it shows no signs of an atmosphere when entering the Sun; it is probably a dead world, airless and waterless, like the Moon.

Two other considerations may be mentioned which tend to support the above suggestion concerning Mercury's origin; first, almost all observers are now agreed that Mercury always turns the same face to the Sun, its time of rotation being 88 days, the same as its year. Undoubtedly the tides raised by the Sun on Mercury have played a part in bringing this about, but it would be a help to suppose that the rotation had first been slowed down by the action of Venus; secondly, as we shall see below, the albedoes, or degrees of whiteness, of the Moon and Mercury are nearly the same, so that they may well have had a similar history.

The word "albedo" is used to express the reflective power of a planet's surface, or the fraction of the sunlight falling upon it that it sends back into space. It is by no means an easy matter to find it; it involves the comparison of both Sun and planet with some standard source of light, such as a candle. It is convenient for this purpose to use a diminished image of the Sun, produced by a little silvered bulb. Allowance has to be made for the different distances of the planets from the Sun. The results indicate clearly that the more atmosphere a planet has, the higher its albedo. It is high for all the giant planets, especially for Jupiter, Saturn, Uranus, Neptune, which reflect about half of the light that they receive; the amount for Venus is also one half; that for the Earth is probably somewhat less; that for Mars is one-quarter or less; the Moon and Mercury come at the bottom of the scale with the figure one-sixth or less. An attempt has been made to show the proportions in a picture; it can only claim to be very rough, and we may observe that the disc of plain paper, supposed to represent



[By Arthur Twiddle

SOME REMARKABLE COMETS

A bright comet with a long tail is one of the most striking spectacles that the Heavens present It cannot as a rule be predicted, for most bright comets have periods many centuries in length Comets are believed to consist of dense swarms of meteors, containing much gas which is driven out and repelled by light-pressure when they approach the Sun Sometimes comets have several tails That of 1744 (middle of picture) had six Donati's comet of 1858 is shown in the left-hand top corner, the bright star beside it being Arcturus Coggia's of 1874 is below it The appearance of the head of Halley's in 1835 shown in bottom right corner

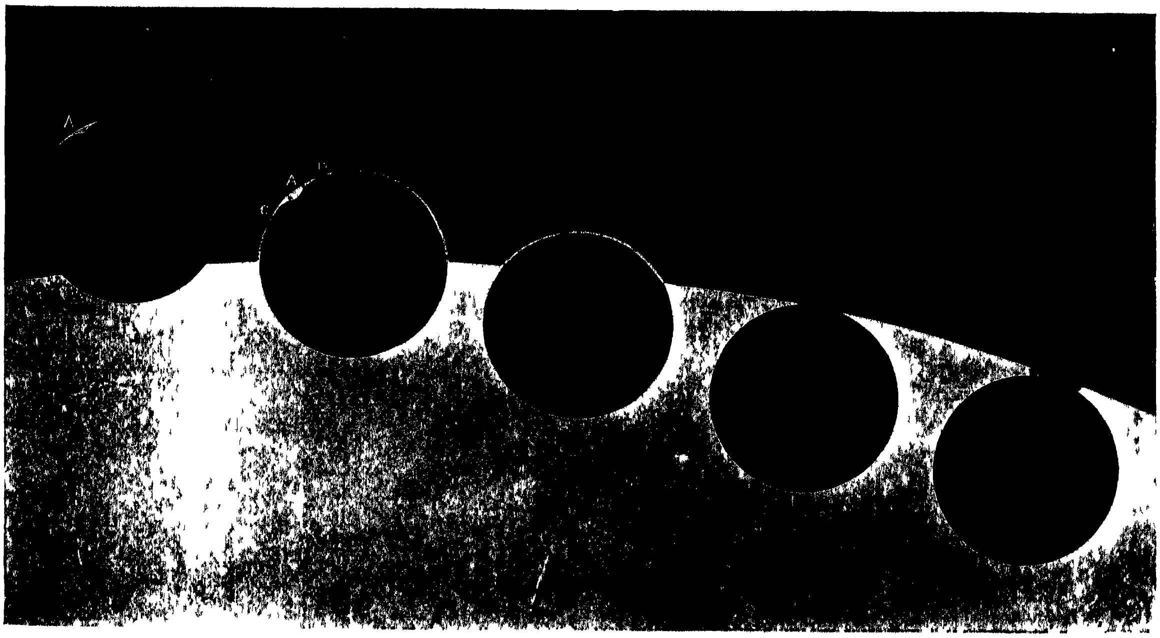
A FIRE-BALL

These are large masses of stone or iron, probably formerly attached to comets, that enter the Earth's atmosphere at a high speed Friction with the air causes them to glow Many of them are entirely consumed before reaching the Earth, but occasionally fragments of them fall to the ground, and can be analysed They are generally found to contain much hydrogen, which may imply that they once formed part of some large orb, either Sun or giant planet, for it is only in these that free hydrogen is found

perfect whiteness, really reflects only six-tenths of the light that falls upon it Newly-fallen snow is the whitest thing we know, but even this has an albedo of only seven-tenths The planets are not equally bright all over, but have brighter and darker patches, the average for the whole surface is used

We cannot see our Earth from outside, but estimates have been made in two ways by measuring the faint light which the Earth throws on the Moon when nearly new (the appearance is sometimes called " The old Moon in the new Moon's arms "), and again by studying the intensity of solar radiation at various heights in the air, apparatus for the purpose is sent up in small balloons, which rise to a height of some 15 miles

It is important to note that when there is a high albedo, much of the sunlight and heat is reflected away from the upper air, without reaching the surface at all The lower albedo of Mars, due to the thin air and small proportion of cloud, means that most of the sunlight that falls on the planet is available for warming its surface, hence we can understand the snow melting rapidly in the long continuous day at the poles, and the fact that in lower latitudes the temperature appears to rise considerably above freezing point in the daytime, though there must be very severe frosts at night



VENUS ENTERING ON THE SUN

This picture shows on a large scale the appearance presented at a Transit of Venus While part of the planet is still outside, it is seen surrounded by a bright ring due to sunlight bent by the planet's atmosphere When the planet has entered on the Sun a dark shading is seen between it and the Sun's edge It is very difficult to fix the instant of true contact

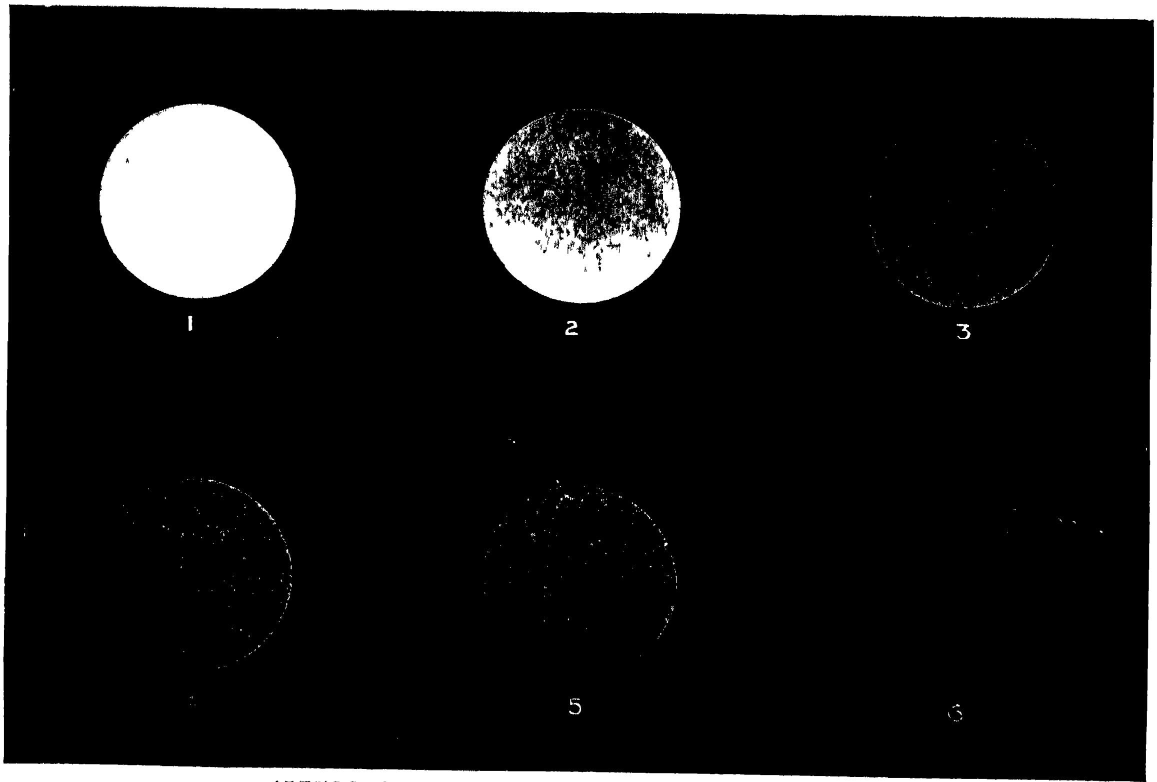
The Moon looks so bright at night that it is hard to believe that its reflective power is so low But contrast with the blackness of space makes it look brighter, and the increased size of the retina of the eye at night, described by Dr Steavenson, also plays a part When we see the Moon in the daytime we notice that it is very decidedly less bright than white clouds, when seen close to a sandstone cliff, the brightness of the two has been found to be nearly the same Proctor remarked that if the Moon were covered with black velvet it would still appear white at night, though much less brilliant than it actually looks

I conclude this chapter by explaining the law of planetary distances put forward by Titius and Bode, it has played a part in history by inciting astronomers to search for a planet between Mars and Jupiter, and it is also a help in committing the planetary distances to memory

Write down the series of numbers 3, 6, 12, 24, 48, 96, 192, 384, each number is double the preceding one, add 4 to each, and also write 4 before the series, we obtain 4, 7, 10, 16, 28, 52, 100, 196, 388

Taking the distance of the Earth as 10, the other numbers represent quite closely the distances of the several planets The law was put forward before the asteroids or the two outer planets were known, it suggested an obvious gap between the orbits of Mars (16) and Jupiter (52) When Uranus was discovered by Sir W Herschel, its distance was found to fit very well with the law, thus strengthening the conviction of a missing planet, so that a society of astronomers was formed, who mapped out the sky between them, in the endeavour to locate it, Piazzi, who found Ceres, was not actually one of this company, but he was no doubt inspired to some extent by their zeal Bode's law agrees well both with Ceres and with the average asteroid orbit

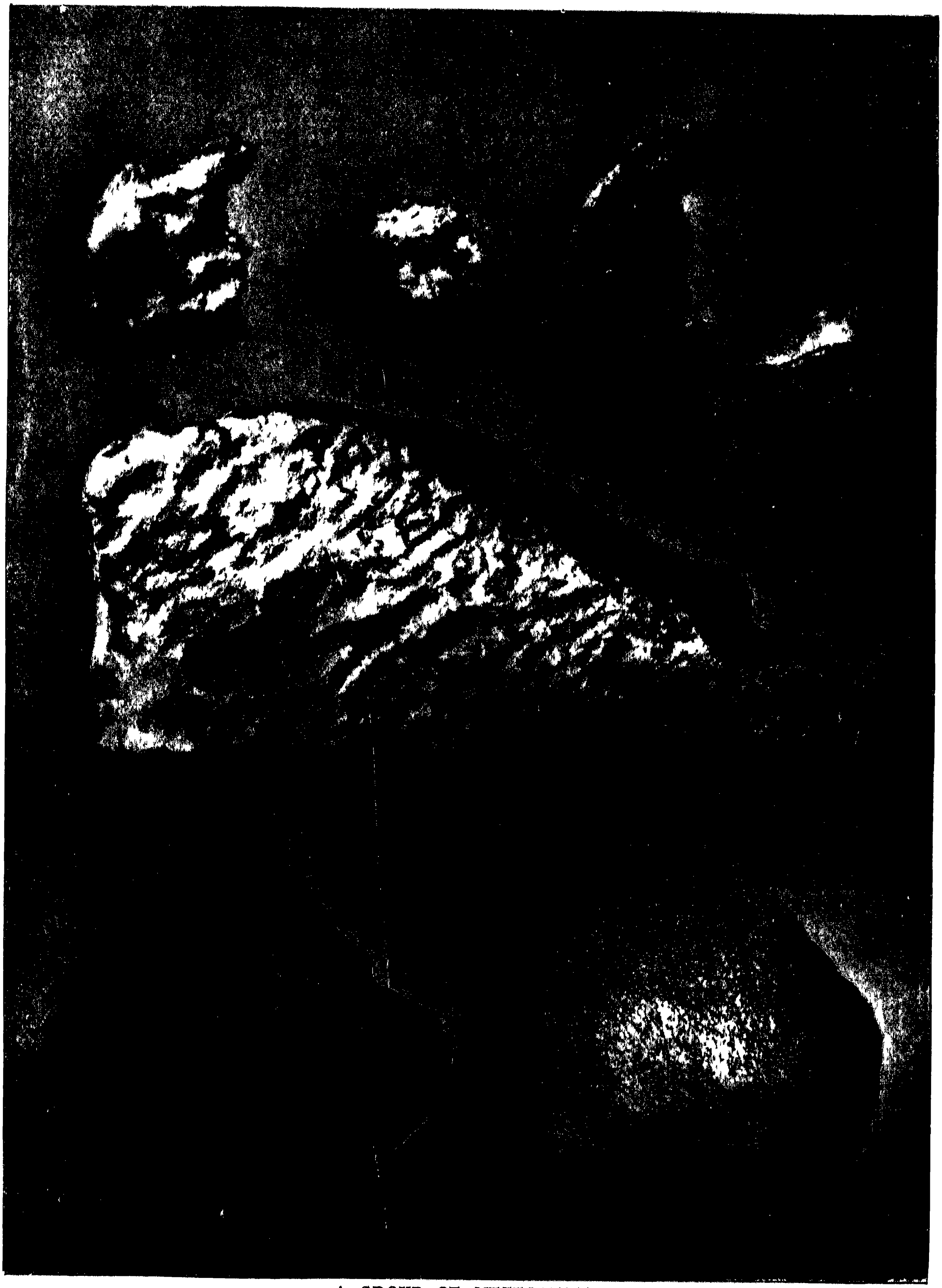
When Uranus had been observed for many years it was found to deviate from the path laid down for it, both Adams and Le Verrier conjectured that an external planet was disturbing it, and calculated



ALBEDO OR REFLECTIVE POWER OF THE PLANETS

Disc 1 is intended to represent perfect whiteness Disc 2 the reflective power of Venus, Jupiter, Saturn, Uranus, Neptune Disc 3, that of the Earth Disc 4, that of Mars Disc 5, that of the Moon Disc 6, that of Mercury Planets with extensive atmosphere are brighter than those without

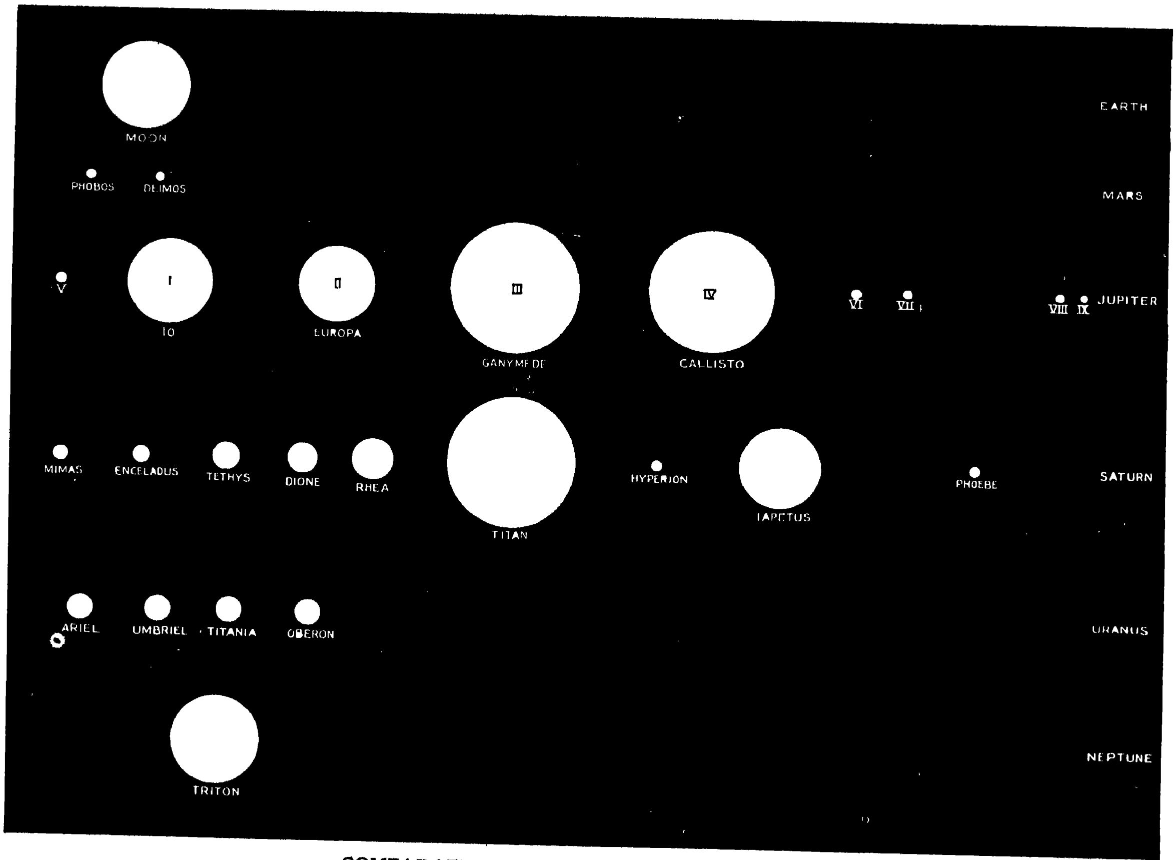
the position of the latter They both assumed the distance of the unknown in accordance with Bode's law, though shortly before the actual finding Adams concluded that its real distance was smaller, the true distance, in fact, is 301 instead of 388, so that Bode's law breaks down badly here Possibly the failure indicates that we have reached the boundary of the family of planets It is at least certain that there is no planet as large as Neptune for a very considerable distance beyond it, if there were, its disturbing effects on Neptune and Uranus would have been recognised There are no irregularities in their motion approaching in size those exhibited by Uranus before Neptune was found Much work has been done in the endeavour to find such a planet, both by a study of these small disturbances and by examination of cometary orbits Each of the four giant planets has a family of comets, whose orbits are grouped in a special manner with regard to its orbit Now there are signs of similar comet groups at greater distances, which may possibly indicate the existence of planets Repeated telescopic



A GROUP OF METEORITES

These are some of the large Fire Balls that have fallen to Earth, and are preserved in our Museums They are of singular interest, for in them we can actually touch and handle objects that have certainly come from outer space, and that may, not improbably, have once formed portions of other worlds The fact that iron is such a frequent ingredient of meteorites shows that it is one of the most important elements in world structure

search has been made for such bodies, if they exist, the numerous photographs that are now taken of the heavens will probably reveal them sooner or later In a photograph with long exposure a planet is distinguished from a star by its appearing as a short trail, in consequence of its motion during the exposure This is, in fact, the usual method of finding minor planets, their motion is, however, much more rapid than that of a trans-Neptunian planet would be



COMPARATIVE SIZES OF THE SATELLITES
The sizes of the Satellites are shown on the same scale—Phobos, Deimos, Phoebe, and Jupiter V, VI, VII, VIII, IX being somewhat exaggerated The Satellites of each planet are arranged in a line, the planets here being given on the right. Ganymede and Titan are nearly as large as Mercury

CHAPTER III

THE SUN AND SUNSPOTS

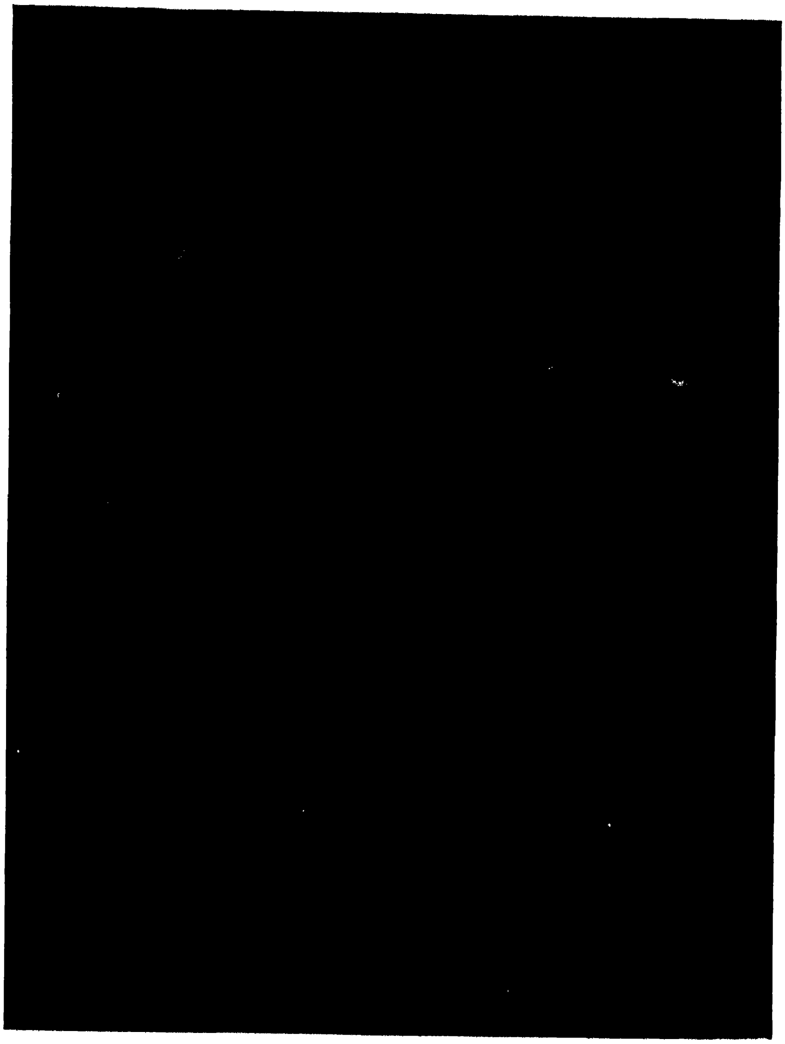
By A S D Maunder, F R A S

THE history of the progress of knowledge concerning the Sun and its surface—at least so far as Europeans are concerned—falls into three sharply defined periods From the beginning of the world up to the year A D 1610, it was known that there was a Sun From 1610 to 1826, it was known that sometimes there were spots upon the Sun, and that it rotated on its axis In 1826, Schwabe began his systematic study of the Sun's surface, out of this has grown all that we know of it to-day

From the days of Ptolemy to those of Tycho Brahé, men in Europe were not observers of the heavens They accepted the dictum of Socrates to Simmias " We neither hear nor see anything

with accuracy If, however, these bodily senses are neither accurate nor clear must it not then be by reasoning, if at all, that any of the things that really are become known to it? And surely the soul then reasons best when none of these things disturb it, neither hearing, nor sight but it retires as much as possible within itself and it aims at the discovery of that which is"

This being so, it is to the Chinese Annals that we are indebted for observations which lead us to believe that before the year A D 1610, there were sometimes spots upon the Sun In the twelfth volume of the "Observatory Magazine," Mr S Hirayama of the Tokyo Observatory has collected together these early sunspot observations, 95 in number, between A D 188 February 14, and 1638 December 10 The usual description is "fleckle in the Sun," but five times the spot is described as "bird-shaped" or "flying bird-shaped," twice as "egg-shaped," and four times as "like an apple" From our knowledge of sunspots to-day, we can guess what these descriptions represent The "apple-shape" is a round "regular" spot, in the "egg-shape" we recognise the great complex spot of solar activity near its maximum, longer than it is broad, drawn out in solar longitude, in the "flying bird" we have the great bipolar stream with its "leader" spot and "trailer" spot

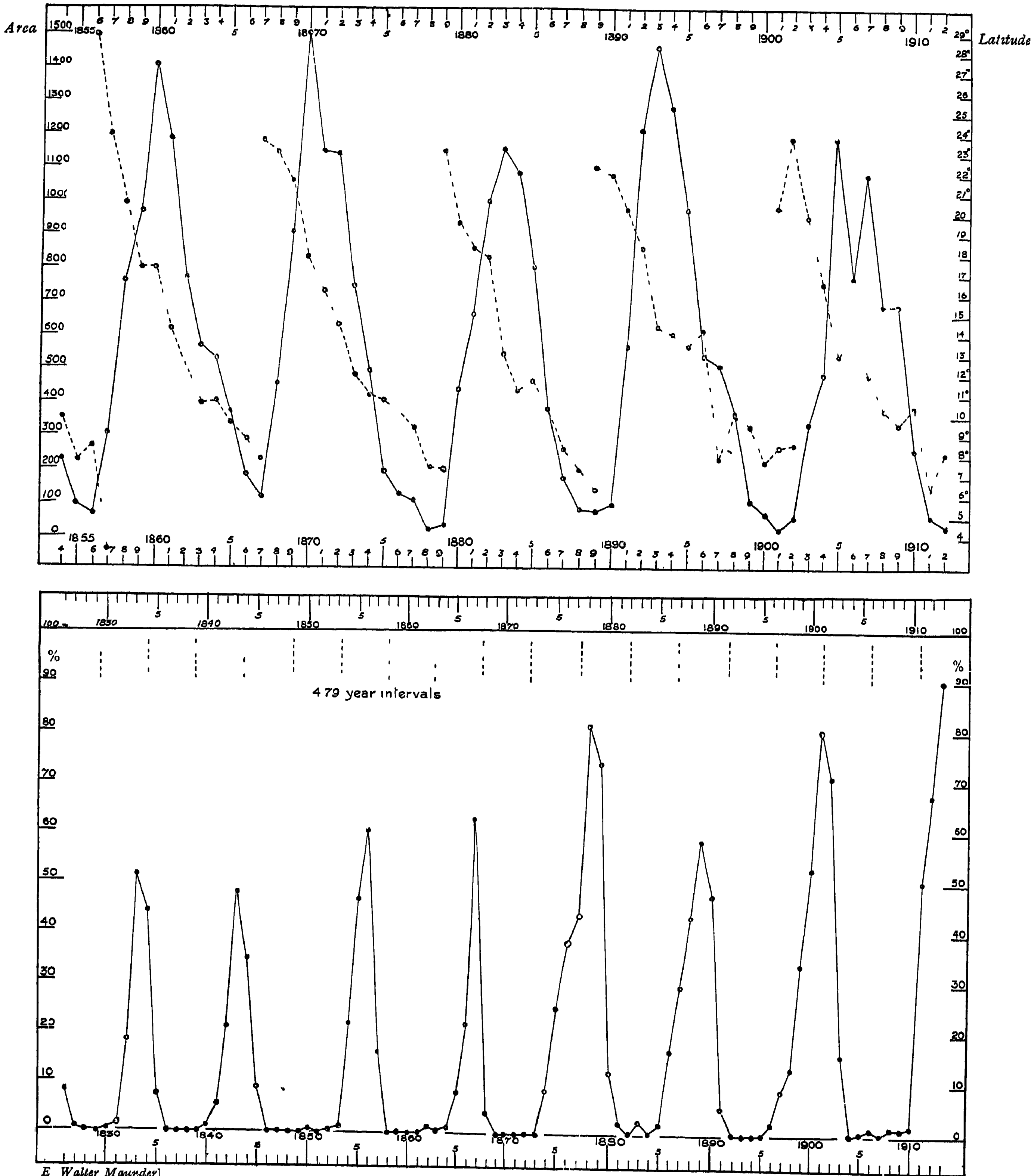


[By Max Rasbil

AURORA BOREALIS

In England, Auroræ are only seen when there is a great Solar Disturbance, but in regions nearer the north magnetic pole they are of frequent occurrence The writer has often seen in Labrador the whole sky shivering with lights and shadows (as above) as if ghostly soldiers patrolled behind misty battlements

With but 95 spots recorded in 1,450 years, there are gaps, sometimes of several centuries, between two consecutive observations Knowing some laws of sunspots to-day, it is interesting to see if any of these laws held good then In the last five solar cycles, the maximum of activity has recurred in a mean period of about 11½ years Professor Newcomb derived an average period of 11 1 years from all recorded observations A mean period of 11 06 years suits the Chinese records above, but the "apple-shaped" records give 11 03 years, the "egg-shaped" 11 07, and the "flying birds" fit very neatly into 12 22 years On the whole we may suppose that something very near our present cyclical period has held good throughout the whole of our era, though there is a suspicion that it may have lengthened



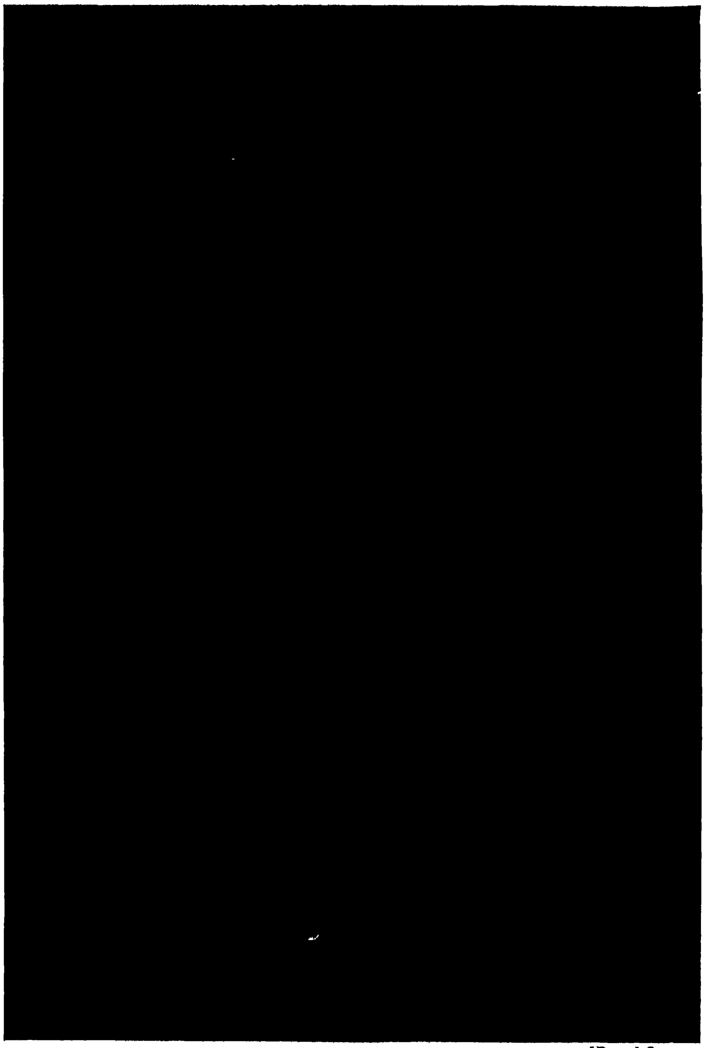
E Walter Maunder] [Royal Astronomical Society

SPOERER'S LAW

In the top diagram, the broken line giving the mean latitude of spots for the different years shows that each pulse of Solar activity is distinct from the one before and after it, and that it begins in high latitude (when spots are fewest) and ends in low latitudes just as the next pulse begins The continuous line gives the area of spottedness, and it will be seen that its peaks, indicating maximum spottedness, come in those years when the broken line shows the mean latitude to be between 13° and 18° The lower diagram gives the percentage of spotless days, and it shows that there is no doubt when the year of Solar minimum falls between 1826 and 1912

These sunspots must have been very large and the conditions for seeing the Sun's surface must have been very appropriate for the Chinese to have been able to observe them at all With the naked eye, we can only see spots on the Sun's surface when its brightness is toned down by fog at midday or by the horizon haze at sunrise or sunset In the 1,450 years of the Chinese Annals, the number of sunspots observed in each month is as follows —January, 15, February, 9, March, 17, April, 11, May, 7, June, 2, July, 1, August, 12, September, 2, October, 7, November, 8, December, 14, from November to April, 74, from May to October, 21 Or three times as many sunspots were observed in the six winter months as in the six summer months Of the "flying-bird" shaped spots, which would need very steady, but foggy, conditions, one was seen in January, three in February, and one in April Also since the Sun is nearer to us in winter than in summer, it appears very slightly larger, and the shape of the spot might be better seen

Are we to infer, then, that if the Chinese had had, during those 14 centuries, a sufficient number of calm, cloudless, but foggy days, we should have had a regular succession of "bird-" or "apple-" or "egg-shaped" markings showing themselves in groups of three or four years which followed each other at intervals of 11 or 12 years? Probably, but not certainly, because a phenomenon occurred in the period 1610–1826 of an order quite different from anything that has presented itself since



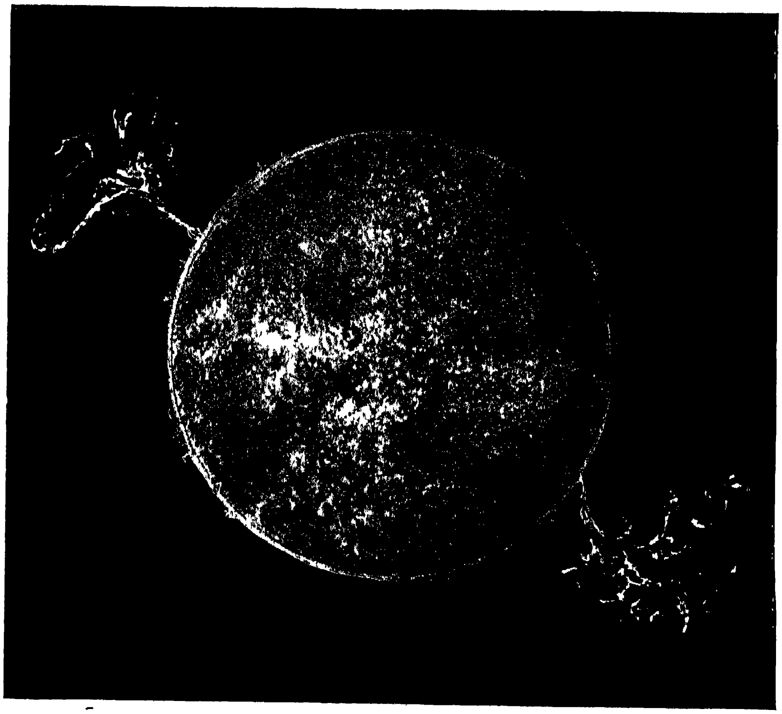
[Royal Society.

AURORA AUSTRALIS

This fine "Draped" Aurora was taken by Capt Scott on his Antarctic Expedition As a rule, if there is a great display of the Northern Lights, the Southern Lights are in evidence also Auroræ are closely connected with great magnetic storms, which are, as far as we know, simultaneous over the whole Earth

With the invention of the telescope in the first decade of the Seventeenth Century, there were three claimants to the discovery of sunspots—Fabricius, Galileo, and Scheiner, and to the last the credit is rightly due, as he was the first to devote himself to a long, steady and continuous survey of the Sun's surface As a consequence there followed the discovery of the rotation of the Sun, the determination of the time (28 days) in which it appeared to rotate as seen from the Earth, and the position of the solar axis But neither Scheiner nor any of his successors seem to have had any suspicion that the changes in the solar spots proceeded in a series of undulations The reason for the delay in the discovery of what we now know as "the sunspot cycle," was simply that it does not seem to have been then working in what now we should consider to be its normal manner, and before the middle of the Seventeenth Century the supply of sunspots would seem to have run out.

For the first years after the discovery of sunspots in 1610, the Sun was fairly active, we do not know for certain whether a maximum took place about 1610, but the first minimum noted was in 1619, and it was followed by a well-marked maximum in 1625. The next minimum fell in 1634, and was followed by a maximum in 1639, 14 years after the preceding maximum. Then there was a long quiet period, with a "maximum" in 1650, which consisted of but a few spots. Spots were seen in 1654, August 12, 1655, February 9–21, 1660, April 27–May 9, in 1661, two small groups, and then again none at all until 1671. From this date until the end of the Century, spots were very occasionally observed, and after 1715 spots were frequent, and by 1718 there was a decided maximum. The long dearth of sunspots lasted from 1645 to 1715, or 70 years, and during this time, so far as we know, there was no spot large enough to be seen by the naked eye, all required the use of a telescope for their detection. Therefore the long gaps in the Chinese Annals may not have been altogether due to the weather being unsuitable for looking at the bright Sun, for there may have been long years when there were no sunspots large enough to be seen. But it should be noted that prolonged as was this inactivity of the Sun, yet the few stray spots seen—1660, 1671, 1684, 1695, 1707, 1718—correspond as nearly as we can expect to the theoretical dates of maximum. The average interval between these maxima is 11.6 years, so that the solar pulse of 11 or 12 years would seem to have been beating, though faintly, through the 70 years dearth, just as we can feel its beat also in the records of the Chinese Annals.

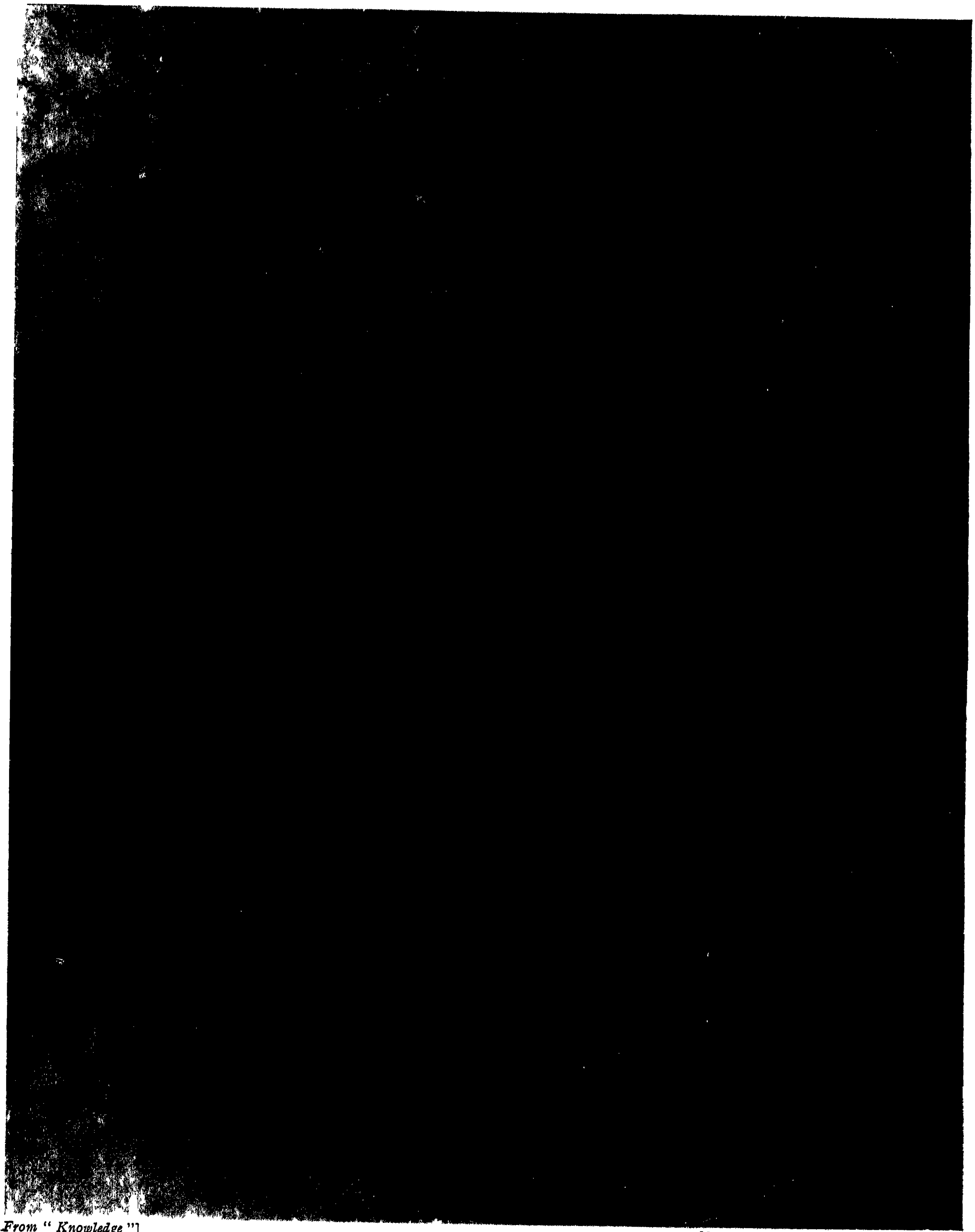


PROMINENCES AT THE ENDS OF A DIAMETER

These great prominences, observed by Trouvelot, illustrate a phenomenon often noticed over the Sun, that disturbances occur at the ends of a diameter. Sunspot streams lie along parallels of latitude, and the writer has often noted spots break out alternately in the Northern and Southern Hemisphere, but in the same longitude.

One point should be noted, for it may have an important bearing on the origin of sunspots. During the dearth, the few stray spots were all, with one exception (April, 1705) in the southern hemisphere of the Sun, it was only when spots came back to the northern hemisphere, in 1715, that the dearth ceased.

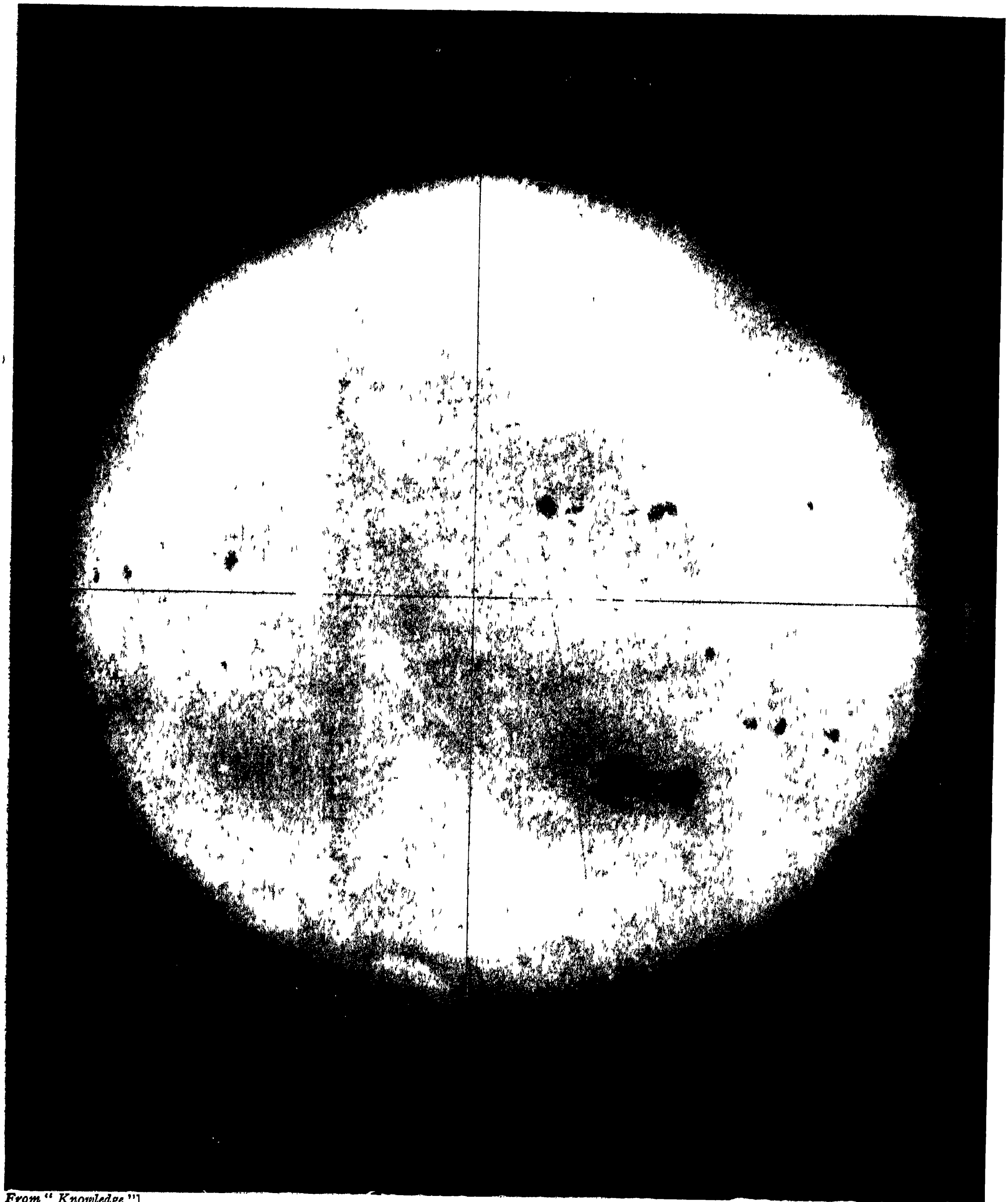
It was more than a century after the Sun had resumed its normal ebb and flow of activity that Schwabe, in 1826, began his study of the Sun's surface. In itself, his work was very simple and straightforward, but it was carried on systematically and with the utmost patience. It was these qualities which made it great and epoch-making. He made a persistent daily count of sunspots. From 1826 to 1913, the days with no spots were few as compared with the number of spotted days, and so they are easier to mark. Accordingly page 112 exhibits for these years the percentage of the days of observation upon which the Sun was spotless. It is obvious that in these 88 years there have been eight epochs when there was a most marked absence of spots, and the dates of these are very clearly defined, in no case is there any doubt as to the year when the Sun was at its quietest. But the



From " Knowledge "] [*By permission of the Astronomer Royal*

A GREAT SUNSPOT

This great Sunspot was photographed in August, 1906, and was visible by the naked eye if this were screened by dust, haze or a dark glass from the full glare of the Sun To the naked eye all its complexity would show only as a round black dot, and it was such a spot that the Chinese observers described as " apple-shaped " Note the dark centre (called the *umbra*), and the grey penumbral fringe The right-hand edge of the Spot is well defined, but the left-hand portion is breaking up to form irregular spots with faculous clouds in between



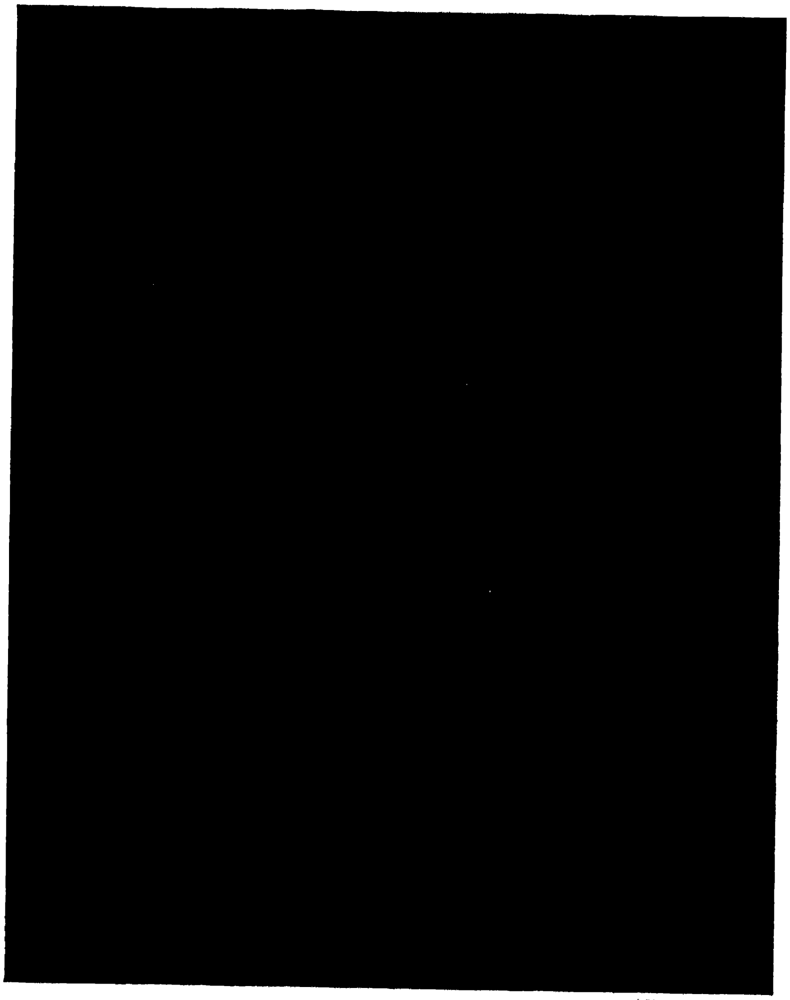
From "Knowledge"] [*By permission of the Astronomer Royal*

THE SUN IN AUGUST, 1893

A photograph of the Sun taken in 1893, August 9 Note the spider lines photographed in the focus with the Sun so as to give points of reference from which to measure the position angles of the spots and faculæ After the exposure, the clock was stopped, and when the Sun had almost travelled off the plate, a second exposure was given, and the lens-shaped marking on the Sun's western limb represents the small portion of the Sun thus photographed to give the east and west line The large group in the S W quadrant measured 2,500 millions of square miles on this day

range in time of the interval between one minimum and the next varies from 10 to 13 years. The average length of the interval is 11.4 years—a little quicker than the beat of the solar pulse during the great dearth; a little slower than the beat given by the Chinese Annals.

This interval in solar phenomena, the mean period of which has been taken as 11.1 years, is called "the sunspot cycle." The recognition of it belongs to Schwabe. Schwabe's work was continued at Zurich, first by Wolf and later by Wolfer, and for them, observers scattered over the Earth counted daily the spots and groups of spots on the Sun's surface, disregarding their positions and the differences between the Sun's northern and southern hemispheres. But as different observers used telescopes of different powers, and it was evident that smaller spots could be detected by, say, a 4-inch glass than by a 2-inch, Wolf deduced a factor for each instrument whereby all the observations could be made to conform to the results that would be obtained by a telescope of a standard power; and Wolf's "Relative Sunspot Numbers" are used in many enquiries wherein long continued and systematic data are required.



[By Max Kaebel

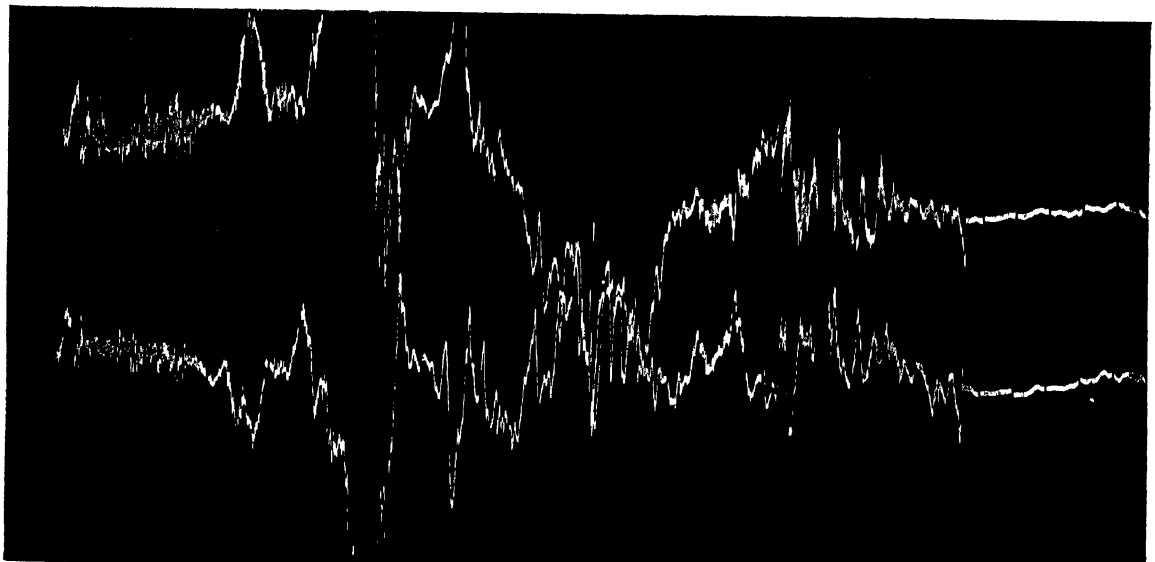
A "DRAPED" AURORA

The most frequent colour in polar auroræ is white, more or less tinged with yellow; and the more vivid the aurora, the more distinctly yellow it is. After yellowish white the next most frequent colour is rose carmine. The "Draped" Auroræ, which are the richest in colour, are only seen in regions whose seas are ice free and therefore liable to fogs.

In the Chinese Annals there is no hint that spots may not occur anywhere on the Sun, and only occasionally a hint that they may have a definite shape. Scheiner found, however, that spots seemed to move along larger or smaller chords of the Sun's circle, but never on very small chords. In fact, the Sun was turning on its axis and spots avoided the polar caps of about 50° radius, both in the north and the south. All spots, too, had their specialities of shape and size, and they differed greatly in these and in the length of time they lasted. The most stable spots, those that change least and last longest, are nearly round. They appear black in the centre, which is not quite half as broad as the entire spot. In this black region (the *umbra*) there are sometimes points of intenser blackness, as if pits were sunk in the floor of a great cavity. Round the umbra is a lighter region, which surrounds it as the iris surrounds the pupil of an eye. This is called the *penumbra*, and is marked throughout by wavy lines flowing inwards, as if the penumbra were made up of thatch straws, which, where penumbra and umbra meet, seem ravelled out into a

narrow fringe. Round the spot, outside the penumbra, the surface of the Sun is brighter than usual, and seems to be heaped up, and some of this bright white stuff may appear to boil over and either flow right across the spot, throwing a "bridge" over it, or else flowing into it. A small patch of this bright stuff is called a *facula*, and is sometimes seen near the Sun's edge, quite apart from any spot. In such cases these faculæ lie in bright patches, like clouds in a "mackerel sky." They are clouds on the Sun, and are near the centre of the disc as well as near its edge, but at the centre the Sun is itself too bright for the brightness of the faculæ to be distinguished upon it.

The round compact sunspot is not the only shape, and spots are generally seen in groups. A very ordinary occurrence is for two very small spots to appear close to each other, to grow quickly and to move apart as they grow; and this movement is so rapid that the two spots may travel away from each other at the rate of about 8,000 miles a day. The "leader" spot is usually round, dark and well-defined; the "trailer" spot may be the larger of the two, but is not so dark or so regular in shape; and between the two a number of small spots spring up and shortly die down again. I think the "egg-shaped" spots of the Chinese Annals were each such a pair of spots, each member



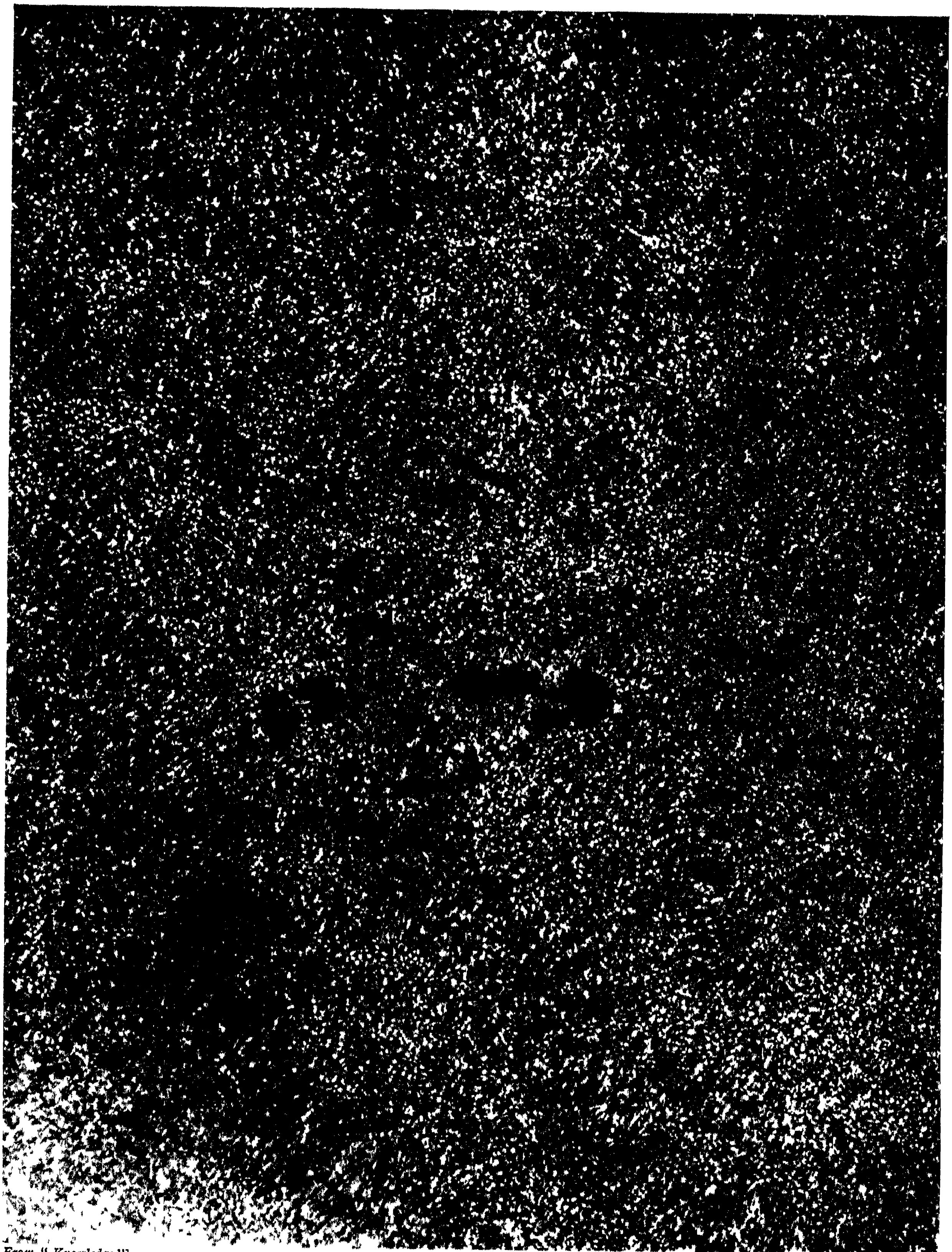
THE TRACE OF A GREAT MAGNETIC STORM [Greenwich Observatory

The magnetic storm of 1892, February 13–14. The magnetic needle is swung in a cellar free from variations of temperature or disturbances from traffic. It responds to the state of the Sun's activity, and on this date a violent magnetic storm synchronised with the passage of a great spot across the Sun's disc. The oscillations of the needle are shown by the ups and downs of the white line in the diagram.

of the pair being large enough to be seen by the naked eye, but the space between them too narrow for them to be seen separately; what the eye perceived was an oval, a little larger than it was broad. Sometimes the spots between the leader and the trailer spots grow as the group lengthens out. Thus there was a great group on the Sun on March 21, 1920, and when the Sun was setting behind a fog bank on that evening the group was visible to the naked eye, but all its immense complexity simply appeared as a single line bent into an angle of 120° in its preceding portion. I think this was just such a case as the Chinese Annals described on five occasions as "flying-bird shaped."

But sometimes also we get a giant spot, single in that any attendant spots upon it are quite insignificant in size, but complex in its whole building up. One or two of such spots have been seen in each of the last five sunspot cycles, always before or at the greatest phase of solar activity. I think the spots which the Chinese Annals described as "apple-shaped" were of this order.

After Schwabe, the next notable sunspot observer was R. C. Carrington, in the years 1853–1861. He redetermined the position of the Sun's axis, and the time it takes the Sun to turn round—or rather

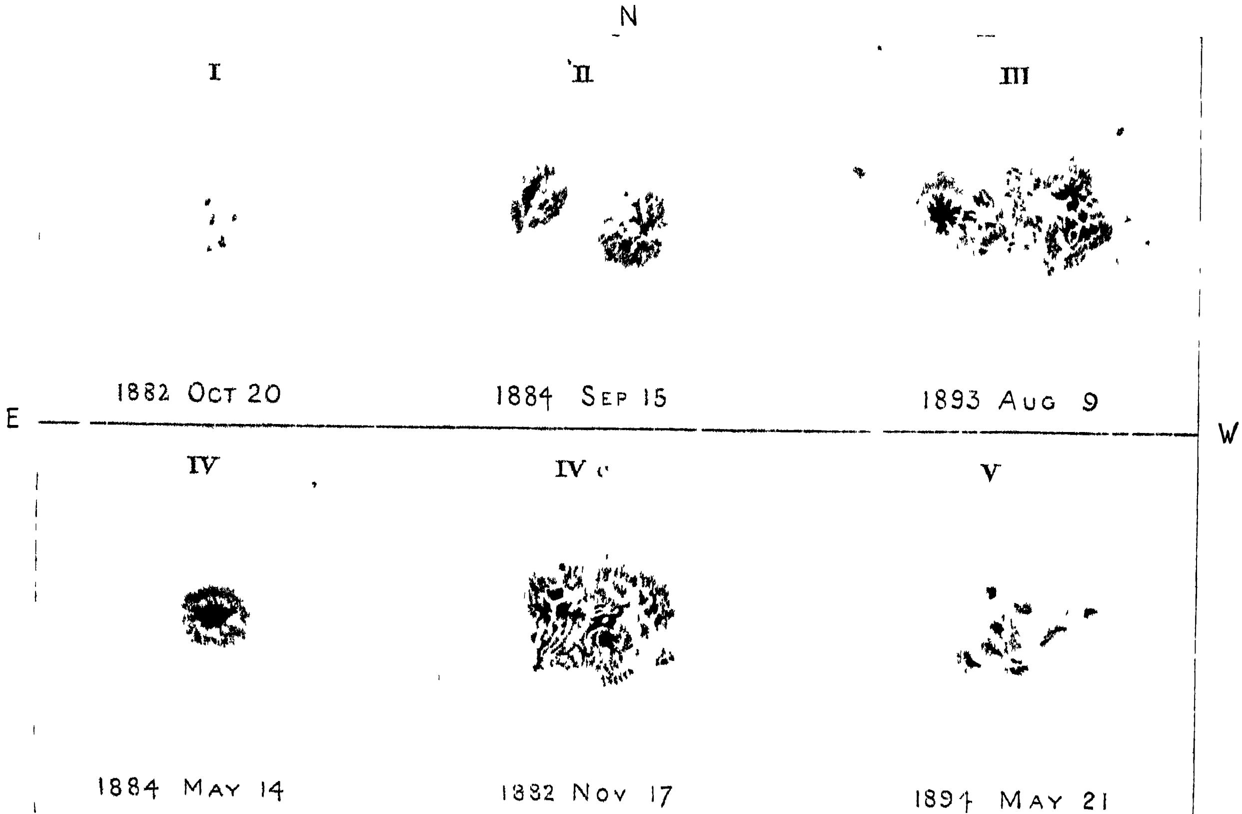


From "Knowledge"]

[*After Janssen*

RICE GRAINS ON THE SUN'S SURFACE

An enlargement of a Sunspot group and the surface of the Sun itself In this case the penumbra of the spot is lost, and nothing is seen but the intensely black *umbra* and the *granules* on the Sun Note that these are in parts well defined, and in parts blurred as if they had been smeared It is not known whether the currents which cause this blurring are currents on the Sun itself or currents of air in the Earth's atmosphere, perhaps in the tube of the telescope itself



Rev A L Cortie, S J] [British Astronomical Association

TYPICAL SUNSPOTS

Drawings by the Rev A L Cortie, of the Stonyhurst Observatory, of different types of Sunspot group Type II is one of the most usual forms, and Professor Hale says that the leader and the trailer spots are of opposite magnetic signs Type III is the form which was probably seen by the Chinese as "egg shaped," and Type IV as "apple shaped"

the times, for he showed that each different zone of latitude, north and south, has its own time of turning Suppose that there were a spot in every fifth degree of latitude from 40° North Latitude to 40° South, and at a given moment all seventeen spots were observed to be on the central meridian of the Sun's apparent disc If, then, each spot travelled westward with the average speed of apparent motion appropriate to its own particular latitude, the spots would all be found after $27\frac{1}{4}$ days near the central meridian a second time, but they would lie on a curved line, not on a straight one

Spoerer's work on sunspots followed hard on Carrington's, and its chief result is known as Spoerer's Law at the beginning of a new cycle, the spots are found chiefly in high latitudes, but as the cycle progresses they tend to slip into lower and lower latitudes until the equator is reached One particular characteristic of this "Law of Zones" he laid stress upon, namely, that the actual sunspot cycles overlap, the new cycle having its beginning before the expiring one has run out its course Both these features are illustrated on page 112, which covers the period 1854–1912, almost five complete sunspot cycles, the material for the first two cycles being derived from Spoerer's own work

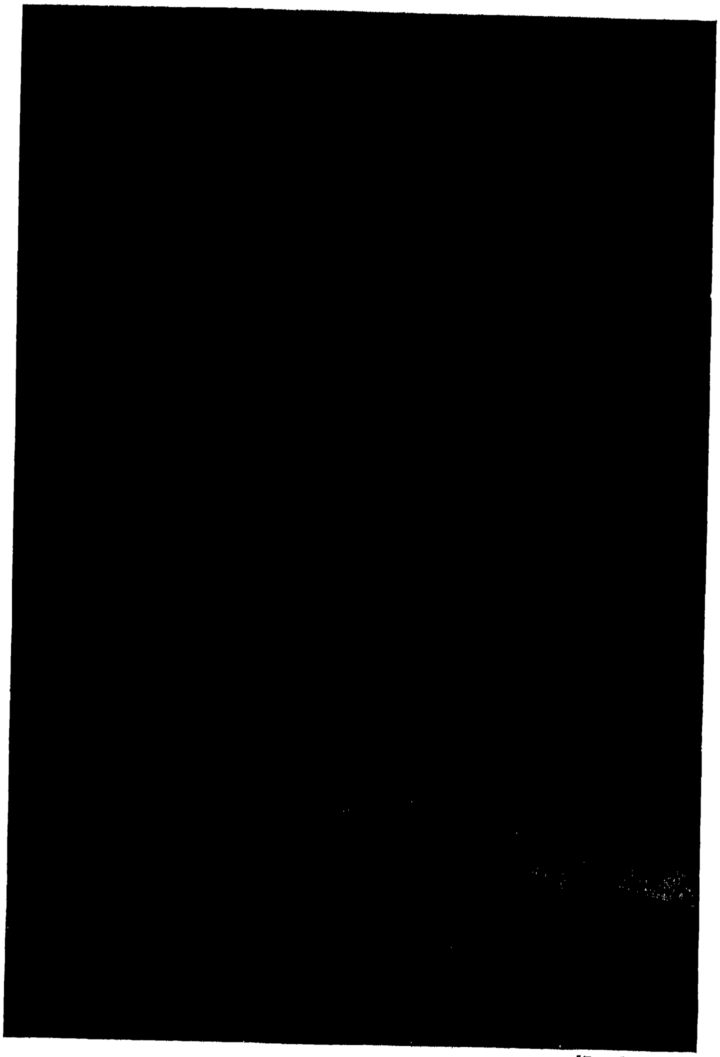
We have already noted that the intervals from maximum to maximum, or from minimum to minimum, are about $11\frac{1}{2}$ years on the average But from the fact that the curve of latitudes is discontinuous, the inference is obvious that each solar cycle is a distinct impulse, and that these successive impulses follow each other quickly, one beginning in high latitudes at about the time its predecessor dies out near the equator The duration of this impulse, like the solar cycle, varies a little, but on the average it is a little over 12 years, perhaps exceeding the solar cycle by about a year

Hitherto sunspot observers had only considered the Sun as a whole, they counted it as a sphere, not as two hemispheres But to Spoerer belongs the credit that he treated the spot outbreaks in the

northern and in the southern hemispheres separately In two papers he traced back his "Law of Zones" to the year 1619, and showed that although there is on the whole a balance between the number of spots in the two hemispheres, yet in three periods of the Sun's history the southern spots have predominated It was Spoerer also who brought out that both the law of the spot cycle and the law of zones were apparently suspended for about 70 years—in the long sunspot dearth of the Seventeenth Century already noted

Scheiner, Schwabe, Carrington, and Spoerer made great advances in knowledge of the laws and conditions of sunspots, and therefore of the nature and constitution of the Sun But their advances were not made because of their powerful instrumental equipment, but because of the patience and continuity of their labours Still, the work of each of these men was personal, and it terminated with the life of each of them

Therefore it was a great epoch in the history of sunspot study, when in 1873, Sir George Airy, the seventh Astronomer Royal, instituted a department in Greenwich Observatory which had as its aim to get a record day by day, continuously, of the Sun's surface by photography on a uniform scale The aim became a practical reality within a few years of its inception, when Sir William Christie, the eighth Astronomer Royal, laid other observatories, in parts of the world remote from Greenwich, under contribution to fill up the gaps inevitable from bad weather in these Islands At present the Royal Observatory at the Cape and two observatories in India, also take daily photographs of the Sun on the same scale as those at Greenwich, that is eight inches to the diameter of the Sun's disc The photo-heliographs with which these daily photographs are taken are very modest in size, at Greenwich during the greater part of the time, the aperture employed has been restricted to three inches, with the image enlarged at the primary focus so as to give the required diameter



[Royal Society

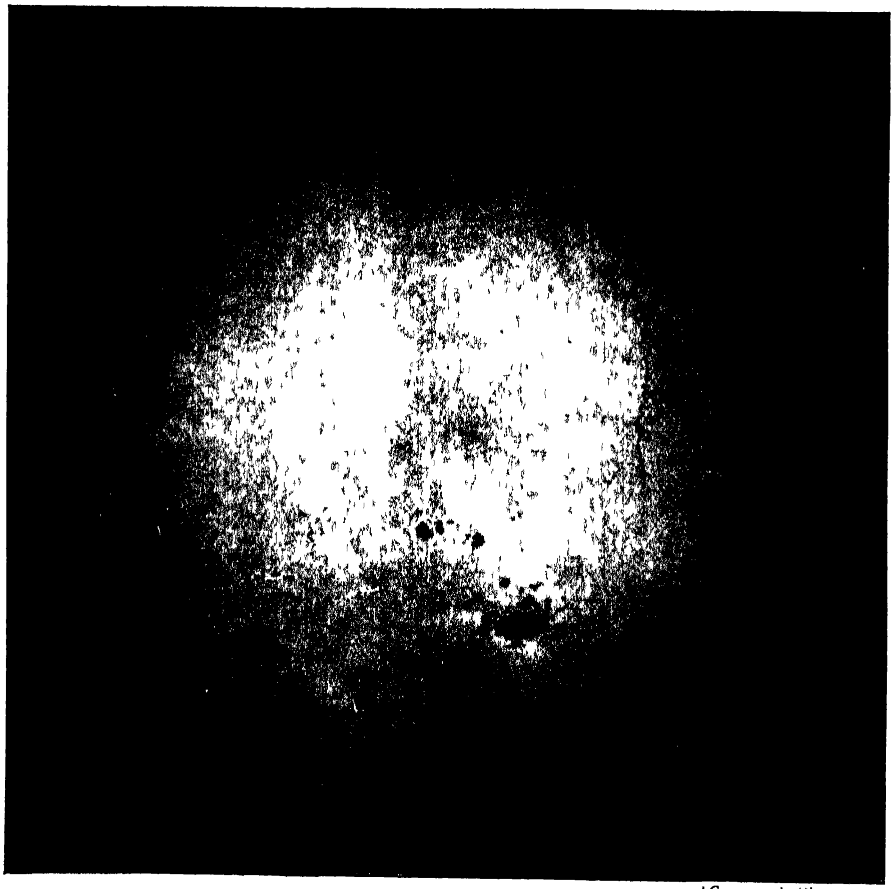
A "DRAPED" AURORA AUSTRALIS

A very fine specimen of the "Draped" Auroræ, observed during Capt Scott's Expedition to the Antarctic All Auroræ which take the form of drapery or fans or undulated arcs, are in general clearly outlined along their lower border, while the light fades out gradually above and mingles insensibly with the sky Mr Gavin Burns has shown that in the years 1916–1919, Auroræ were most frequent when certain longitudes on the Sun were turned towards the Earth

At each of these four solar stations when weather permits, two photographs are taken each day, and these are all sent to Greenwich to be examined, measured,

and the measures reduced It may seem a great waste to have eight photographs taken when, in practice, only two are required and only one measured, but the waste is inevitable and necessary if the continuous daily record of the Sun's spots is to be made and kept complete This number of stations is, however, sufficient, for it rarely happens that the weather is bad at all four localities on more than one or two days in the year Greenwich can supply a good record for its summer months, and the Cape Observatory for its summer, corresponding to winter at Greenwich, and Dehra Dun and Kodaikanal fill up the gaps in the remainder of the year

The measures of the photographs are made at Greenwich and two complete sets of measures are taken as made by two observers, of whom the one measures with the magnifier on the right of the instrument, and the other measures on the left, the means of the two sets of readings being used in order to eliminate the "personal equation" of the observer and errors in the instrument The measures are then transformed into solar longitudes and latitudes As on the Earth so on the Sun, latitude is an obvious thing, the Sun's equator is almost as easy to determine as the Earth's equator So on the Sun, as on the Earth, we have to choose, by favour, a "prime meridian", none stands out as any more the "first" than the others On the Earth, we choose the meridian of Greenwich as longitude 0°, on the Sun, Carrington took that longitude as the prime meridian which coincided with the centre meridian at Greenwich noon on 1877, February 27, and this is still counted the prime in the Greenwich sun-spot measures But on the Sun there is a further difficulty, all parts of the Sun do not turn in the same time Carrington therefore adopted a certain mean time of rotation, that given by the majority of the spots in latitude 10°–15°, and the time of sidereal rotation (*i e*, as referred to the stars) he adopted was 25 38 days Spots near the equator move as a rule more rapidly than this, spots in high latitudes more slowly

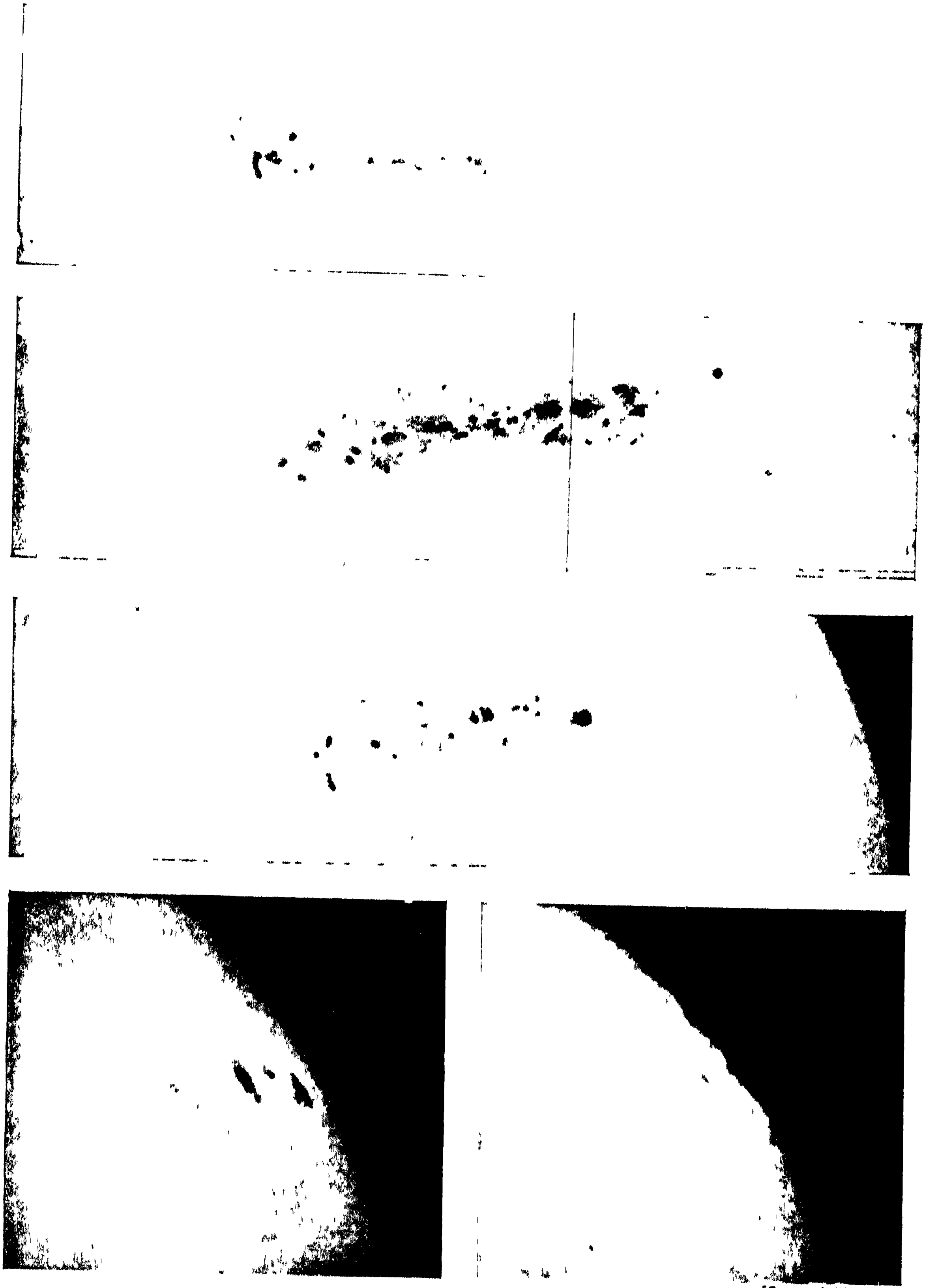


[Greenwich Observatory

THE GREAT SUNSPOT OF FEBRUARY, 1892

The great Sunspot of 1892, February 13, which ushered in the maximum of the Solar cycle, 1889–1901 A few hours after this spot had passed the Central Meridian of the Sun's disc, the violent magnetic storm broke out of which a tracing is given on page 118 The spot passed off at the western limb, and a fortnight later came into view again at the eastern limb, and when it had again passed the Central Meridian, the magnetic storm broke out again violently for the second time

For the first 12 years of the photo-heliographic work at



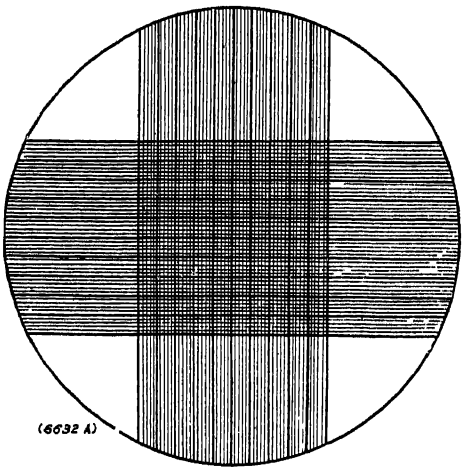
[Greenwich Observatory

A LONG SUNSPOT STREAM

A series of photographs of the very large stream of 1896, September 10–22, showing it fully presented when passing the Central Meridian, when nearing the western limit and when quite close to the edge, and when disappearing into the unseen hemisphere. This long-drawn-out form of spot group is typical of that part of the Sun spot cycle when Solar activity is on the decline. Such a stream might be seen by the naked eye as a line on the surface of the Sun, and it was probably such a group that the Chinese described as "flying-bird shaped."

Greenwich the measures of the spots and faculæ were printed after reduction in the form of a *Journal*, called the "Daily Results" Each separate spot and facula is there given in the order of solar longitude, with its solar latitude and its area expressed in millionths of the Sun's visible hemisphere The faculæ are somewhat formless, like the clouds on the Earth, they have no lasting distinctive features But the spots are often, indeed usually, associated in groups, and can be recognised from day to day, and these sunspot groups each receive a distinguishing number

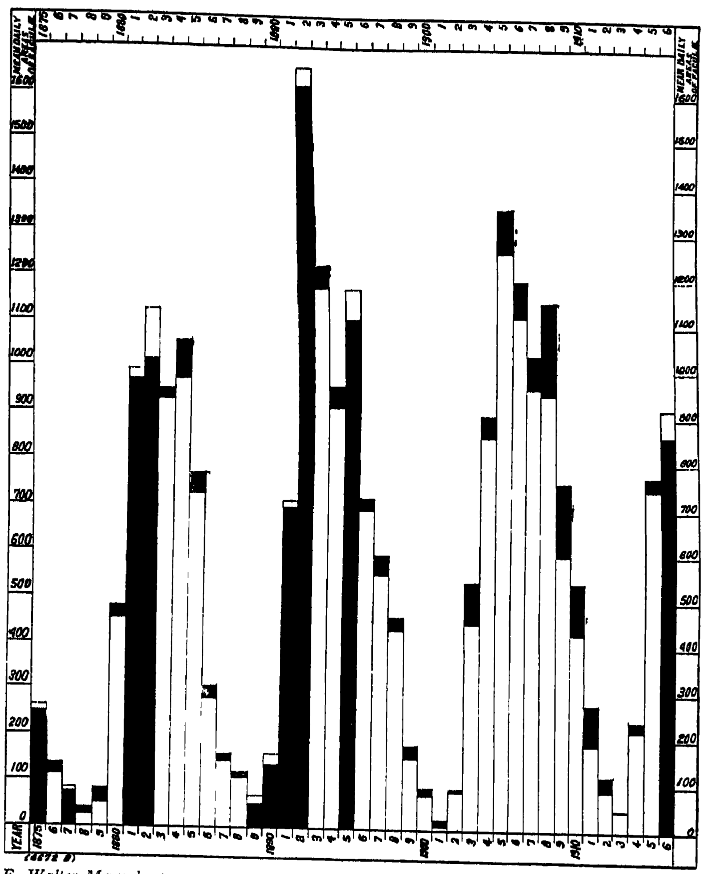
It soon became evident that spot groups differ among themselves in many particulars, they may live for a few minutes or days or many weeks, they may seem no larger than pin-heads—minute areas measuring no more than 400 miles across—or they may be torn and irregular blotches, blackening three or four thousand millionths of the Sun's bright surface, huge pits in which a hundred globes as big as the Earth could lie together side by side Evidently, then, much might be learnt of the nature of a sunspot if the measures for each group were collected together for its whole visible life in a sort of "Ledger," so as to bring out its development and history These *Ledgers* were first printed for the Greenwich Results in the year 1886, and have since been published year by year with the *Daily Results* In 1907 the *Ledgers* were extended backwards for the first 12 years, 1874–1885, so that we have now for well-nigh 50 years an intimate knowledge of the behaviour of *all* the spot-groups on the Sun that have been visible from the Earth We have the means of working out the life history of groups of different durations, and the connection between their size and their length of life, of the movements on the Sun of groups of different latitudes, of the centres of activity on the Sun, and whether these favour certain latitudes and



[*E W Maunder*

THE METHOD OF MEASURING AREAS OF SPOTS

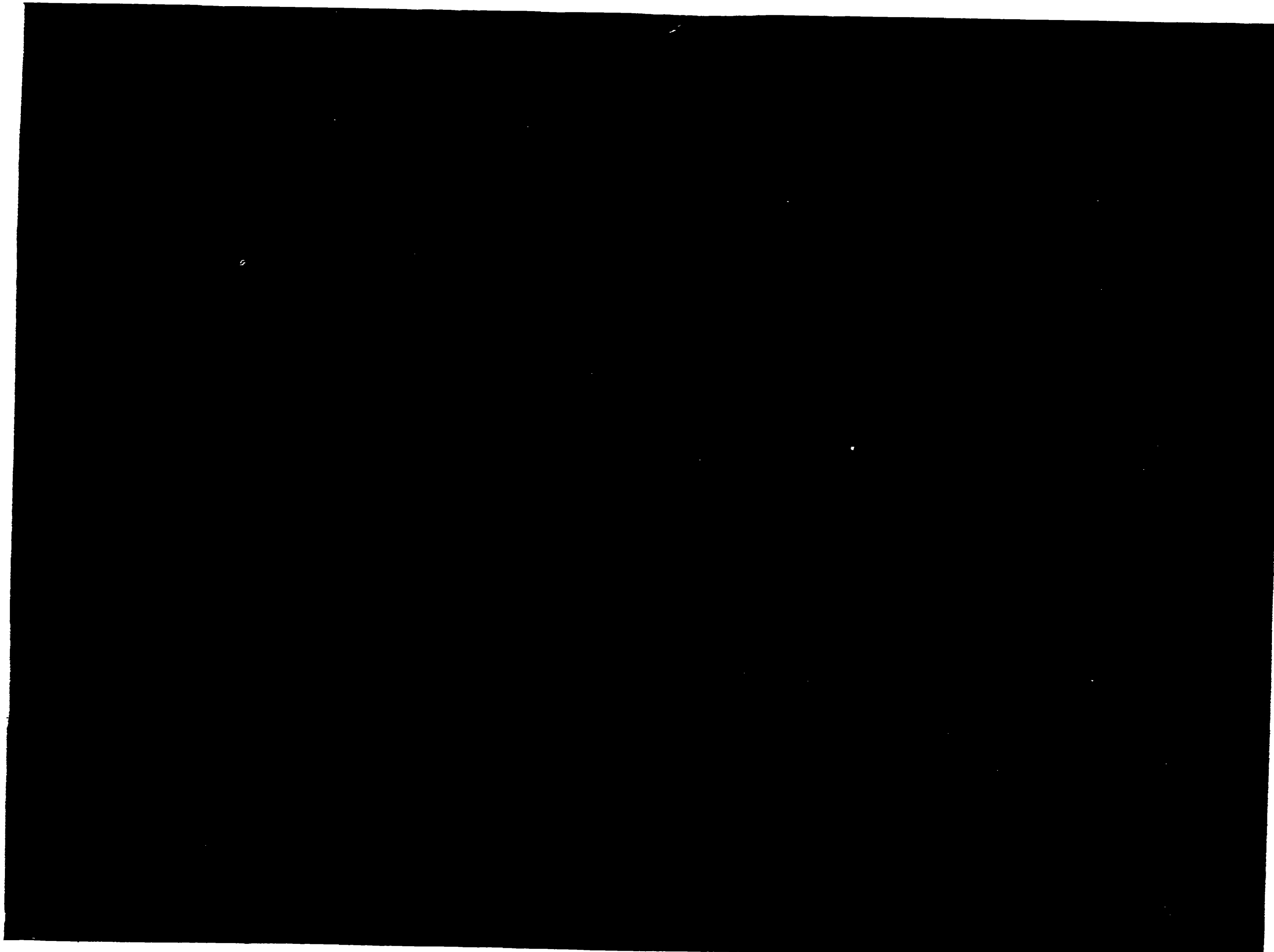
The ruled glass diaphragm with which the areas of the spots and faculæ on the Sun photographs at Greenwich Observatory are measured The number of the squares included in the spot is counted



E Walter Maunder] [*British Astronomical Association*

COMPARISON OF AREAS OF FACULÆ IN THE EAST AND WEST HEMISPHERES OF THE SUN

The white columns represent the mean daily areas of the faculæ on the west limb, the black columns those of the faculæ on the east limb, the shorter column for each year is superposed on the larger one, so that the cap of each column represents the area by which the under column, *i e*, the longer one, exceeds the shorter one



Miss L Martin Leake

DRAWING OF A CORONAL BEAM

The south-west quadrant of the Chromosphere and Corona as seen in the Total Eclipse of 1900, May 28 As seen by the eye, the Moon looked black and was bordered by a narrow rim, known as the Chromosphere, comprised of small tongues of red flame Beyond these stretching out far into space was the petal-like curves of the Corona, bending to each other These are of a silvery radiance, and when the Solar activity is small, they fold themselves about the line of the Sun's equator like two great wings; when the Sun is very active, the Coronal petals spread out in all directions

E Walter Maunder] [*British Astronomical Association*

THE CORONA OF MAY, 1900

A drawing made by the late W H Wesley, Assistant Secretary to the Royal Astronomical Society, from photographs taken by E Walter Maunder, at Algiers, of the total Solar Eclipse of May, 1900 This Eclipse occurred when the Solar activity was almost at its minimum, and the poles of the Sun are clearly indicated by the rays which spread out like a fan On the west two great coronal streamers are seen, on the east one is visible But one of the most noteworthy features of this Eclipse was the black rays, of which three are seen

longitudes, of the relations of these centres of activity with other phenomena on the Sun, or with phenomena outside the Sun, and, perhaps most important of all, we can test the forces within the Sun itself, and we find that they are not monarchic but dyarchic—that the northern hemisphere of the Sun is distinct in its acting from the southern hemisphere, though not independent of it, they both respond to the same cyclical law imposed upon them, but each reacts in a somewhat separate manner, and at a separate time The history of sunspots during the last 50 years is linked with that of the Solar Department of Greenwich Observatory, some advance has been made there in the solving of the solar problems just stated, and the further solving of them depends on the completeness and the continuity with which in the future these records will be kept—kept preferably at Greenwich, for nowhere else in the world has solar work of this nature been carried on for so long a period and with so little interruption

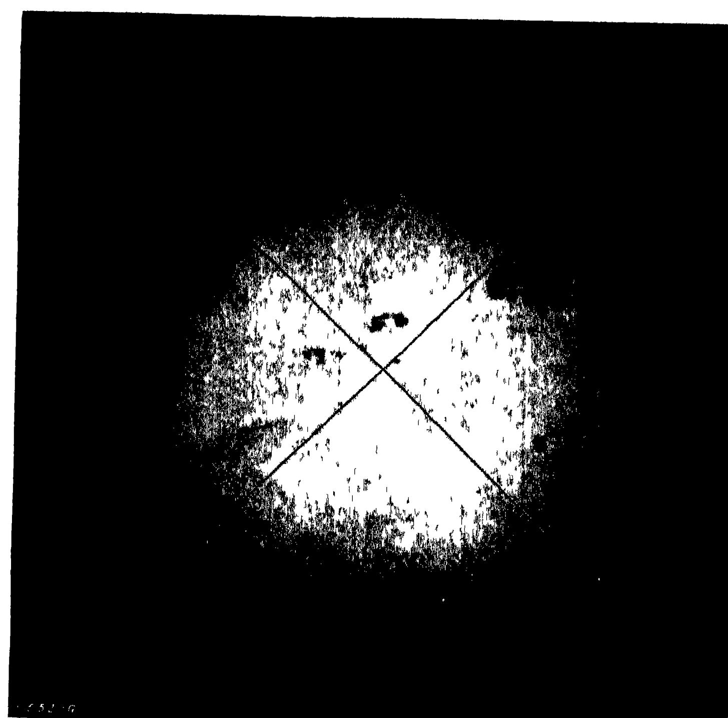
[G W Ritchey

THE RING NEBULA IN LYRA

We see the annular Nebula in Lyra as an almost circular ring with a star occupying its centre According to researches by Major Hubble, at Mount Wilson Observatory, the light of the Nebula is either star light reflected or re-emitted

Let us consider first the way in which Spoerer's Law of Zones is presented by E W Maunder at Greenwich On page 146 appears what has been called "The Butterfly Diagram," for the obvious reason that it looks like three specimens of lepidoptera, and a bit of a fourth, pinned to a board with wings extended, but of which the heads, bodies and legs have mouldered away Each pair of wings is distinct from the next, there is a clear V-shaped gap between each of the specimens

But materials for these wings are drawn entirely from the *Greenwich Photo-heliographic Results*, and they extend over the years 1874–1913 Seven thousand groups of sunspots are represented, but the short straight line which indicates the latitude of a spot is drawn just as long and as heavy for a small spot as for a large one, for one



[Greenwich Observatory

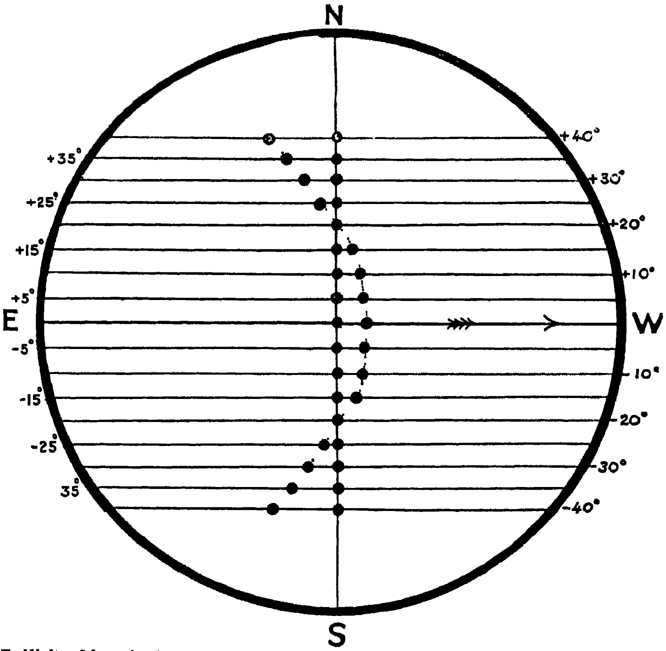
THE MOST SPOTTED DAY ON THE SUN

The Sun showed a larger total spotted area in 1917, August 10, than at any other time during the last forty-eight years The photograph here reproduced is for August 12, on it are four independent groups visible to the naked eye at the same time

spot as for a dozen "The Butterfly" represents only the distribution of spots in latitude, nothing is shown concerning their areas All spots that occur during the same "Rotation of the Sun" are represented in the same vertical line, and the Sun is taken as rotating (as seen from the Earth) in 27 275 days

The V-shaped gap indicates that *each solar cycle is one*, a single impulse that is complete in itself and distinct from the impulses that came in the past or will come in the succeeding years

Next, it suggests that this impulse, the *origin* of the solar spots, lies within the Sun, not without it The spots must come from below the Sun's surface, they are impressed upon it by no exterior influence, neither by planets, nor by meteors No exterior influence could invariably begin a fresh disturbance in a high latitude simultaneously on both sides of the equator

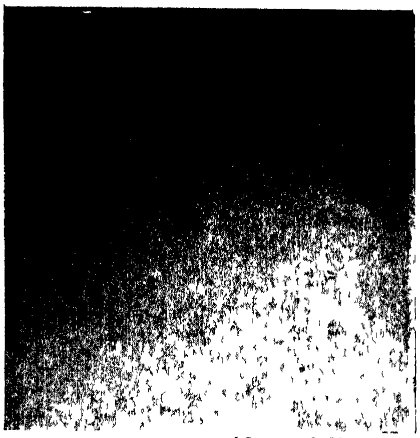


E Walter Maunder] [Royal Astronomical Society

THE ROTATION TIMES OF THE SUN

If on a given date seventeen spots, 5° apart on the Central Meridian of the Sun, as indicated by the vertical line, moved with the rate of their latitude, after one complete rotation of the Sun they would lie on the curved line This shows how much more quickly spots rotate the nearer they are the Sun's equator

This impulse of some force acting within the Sun must lie so deeply and yet so widely within it, that though it begins to act on both the northern and the southern hemispheres at nearly the same times, these actions occur at their greatest distance apart The first spots of a new solar cycle begin almost simultaneously in very high northern and very high southern latitudes, the last spots of a solar cycle are in low latitudes so that northern and southern spots seem almost to merge Indeed, "the Butterfly Diagram" seems to suggest that the solar butterflies have been for the last three or four cycles stronger on the southern wing than on the northern, and that in the expiring phases the southern encroached slightly over the northern at the equator, as if the southern influence—whatever it might be—actually crossed over the equator But the solar cycle now running its course has shown the northern wing stronger than the southern, the strength of the



[Greenwich Observatory

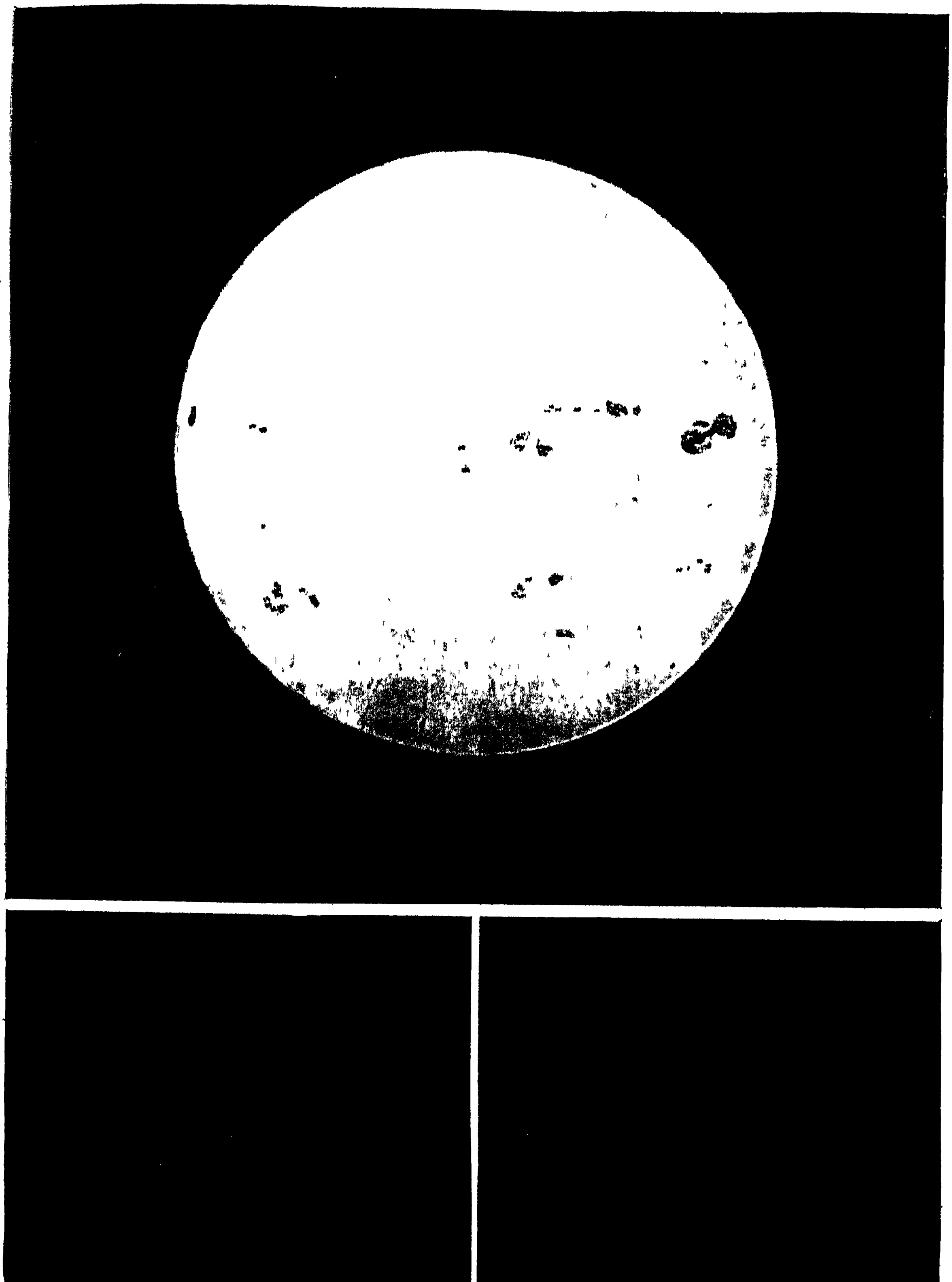
A SPOT FORESHORTENED

A regular spot showing foreshortening near the Sun's limb Note that the *umbra* is less foreshortened than the whole spot

[Greenwich Observatory

UMBRA AND PENUMBRA

A stream of spots Note the black *umbræ* irregularly set in grey penumbræ Note also the gradation of light near the limb



Painted by Arthur Twidle

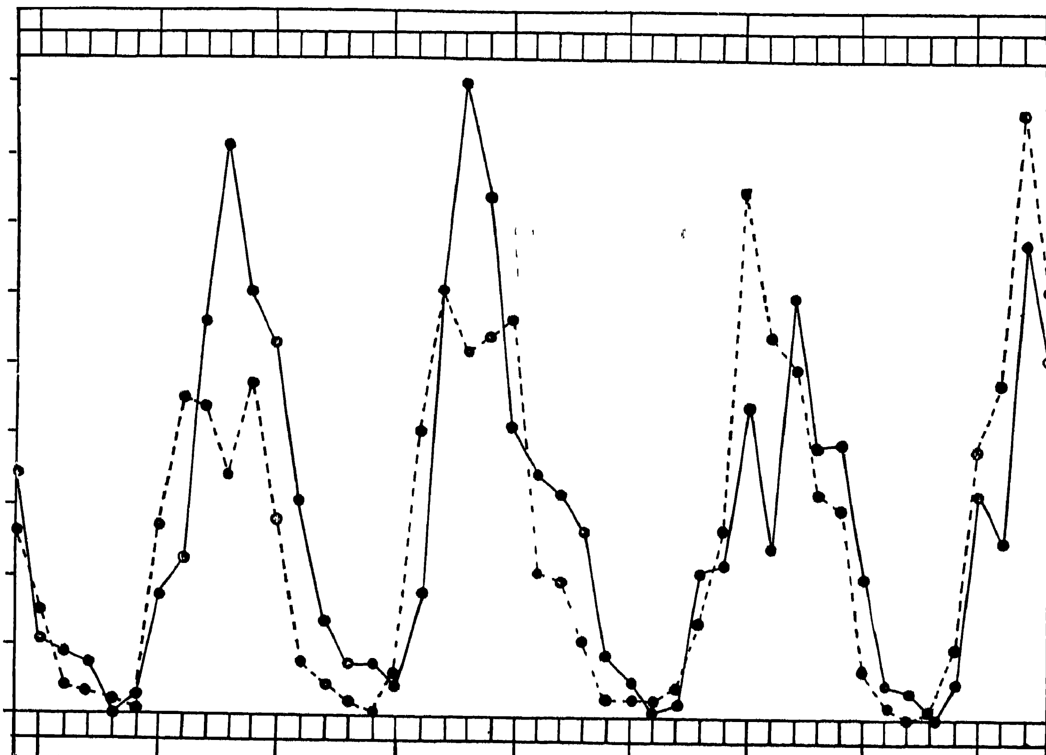
SUNSPOTS, CHROMOSPHERE AND PROMINENCES

The upper picture shows the relationship which we infer to exist between the spots on the sun's surface and the chromosphere and prominences which lie above the spots We do not actually see these two classes of solar features at the same time, for the spots we see on the actual disc with an ordinary telescope, the chromosphere and prominences we see at the edge of the sun with a spectroscope The lower part of the picture shows the forms which the red flames, commonly called the prominences, may assume They may extend outwards for thousands of miles.

forces acting within the Sun have, for the time being, been transferred to the northern hemisphere

We may draw the conclusion that the Sun is not—at least not always—symmetrical in the constitution of its interior There is something deep within the Sun, which makes a distinction between its northern and its southern hemisphere. The solar cycle is one, not merely for sunspots in general, and for sunspots in any special zone in particular, but there is some want of symmetry in its action that makes the northern and the southern hemispheres distinct, they may work in harmony or in discord, but they work somewhat differently

And perhaps the one cannot act without the other, or at least act efficiently It seemed to be so in the latter part of the Seventeenth Century, for during the 70 years' dearth of spots, all that did appear above the surface were southern, except in two cases, both occurring near the end of the dearth



E Walter Maunder] [*Royal Astronomical Society*

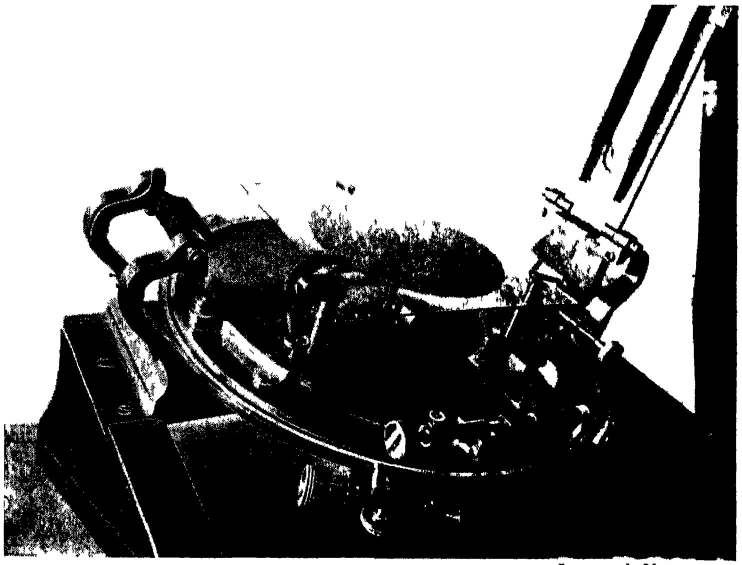
THE SUNSPOT AREAS IN THE NORTH AND SOUTH HEMISPHERES OF THE SUN

The mean daily spotted area of the Sun is shown separately for the northern (dotted line) and for the southern (full line) hemispheres for 1874–1918 It will be seen that the Solar cycle is the same for both hemispheres, though there are differences in details Note that the northern hemisphere is active before the southern, and in the first two cycles has a double hump The southern maximum is greater, but with a single hump In the last cycle the northern hemisphere has the more strongly marked maximum

Perhaps from this instance we might draw the inference that great feebleness in one hemisphere means feebleness in the other also

It is perhaps convenient to introduce here some numerical data about the Sun, and their relations to the Earth On the scale of Earth = 1, we have for the Sun diameter = 109, mass = 333,434; density = 0 26, surface = 11,900; volume = 1,300,000, surface gravity = 28 0 The diameter of the Sun in miles is 864,000 and the area of its visible surface (the hemisphere presented to us) is over a million times a million square miles The period of rotation assumed for the Sun is 25 38 days (Carrington's period), but this is, of course, its period relatively to the Stars, the corresponding

mean rotation is 27 275 days—as it appears to an observer on the Earth, which is itself traversing an orbit round the Sun in the same direction as the Sun rotates The mean apparent daily motion of a spot, with respect to the central meridian on the Sun's disc, is 13° 2 A long-lived spot appears to cross the visible disc of the Sun in thirteen or fourteen days

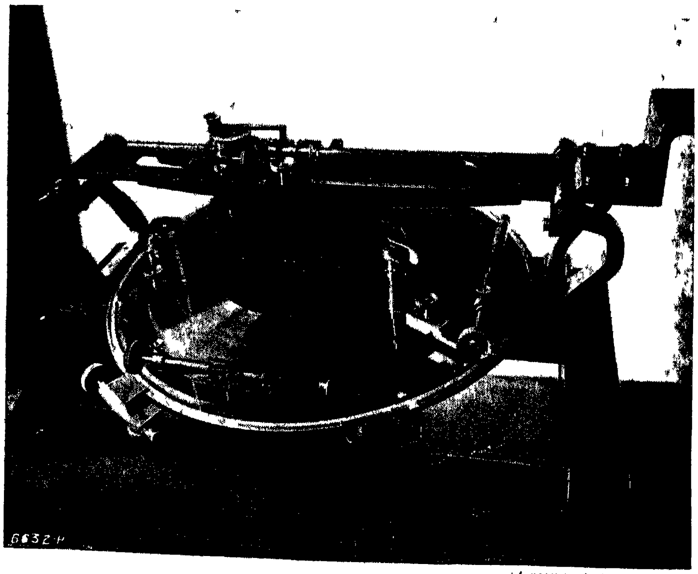


[Greenwich Observatory

THE SOLAR MICROMETER OPEN

The Solar micrometer for measuring the positions and areas of spots and faculæ The slide, on which the glass diaphragm ruled in squares moves, is open, showing a photograph in place, mounted on three pillars with the film side upwards

In 1907, the writer found that the longer lived a spot, the larger is its average size The size of a spot lasting for fourteen days is more than four times that of a ten-day spot, more than eleven times a five-day spot, and more than twenty-six times a two-day spot Also, a spot varies its area from day to day of its history It starts from nothingness, it runs up rapidly to its maximum area, then more slowly it sinks again to zero, though there may be minor fluctuations both in its upward and downward course Thus anyone of these groups of different durations may have come into being at a region on the Sun's surface turned away from us, or it may die out on the invisible hemisphere, its life, apparent to the Earth, may include for the most part its time of rapid growth, or on the other hand its time of slow decline Even the one-day spots may include cases of the first day of a long and active life



[Greenwich Observatory

THE SOLAR MICROMETER CLOSED

The same Solar micrometer with the slide down, and showing the eye-piece, which can move diametrically across the photograph

The writer therefore worked out the history of all the spot groups which lived, or appeared to live, for eight days, dividing them into three categories The Eastern Category includes those which form in the invisible hemisphere, and only the last eight days of their existence are passed on the visible side of the Sun, these are decaying groups, and their chief energy is already passed Next, in the Western Category are those which are born on the visible side of the Sun, and pass, when still active, into the unseen hemisphere These are large and active groups, and they are visible in their first eight days of life when they are growing most rapidly The Central Category are those which are born and

which die on the visible hemisphere These are the true eight-day groups The areas per day for the three categories are —

Category	Mean area per day in millionths of the Sun's visible hemisphere	No of groups
Eastern	59	67
Western	194	35
Central	47	43

The true mean area of groups which live for eight days is 47 millionths of the Sun's visible hemisphere—that is to say, some 55 millions of square miles, or about six times the area of what used to be the Russian Empire Mark also that the number of groups in the Western Category is about half the number in the Eastern Category, but its mean area is more than three times that of the groups which die in the East

By permission of] [The Astronomer Royal

GREENWICH OBSERVATORY LOOKING NORTH

The original observatory of Flamsteed is seen in the far distance, surmounted by the time ball and wind registers In the middle distance is the great dome of the 28-inch refractor, and in the foreground, the Allazimuth, whose dome is opened (as shown) by sliding the halves apart

We have therefore this point clear For spot groups of this class—observed for eight days—many more come round at the east limb of the Sun from the unseen hemisphere and die on the visible disc, than are born on the visible hemisphere and pass out of sight at the west limb For eight-day groups the mortality on the visible hemisphere is much greater than the birth-rate

Why should this be so? The Sun is constantly turning round as seen from the Earth, there is no central meridian, no eastern nor western edge marked in it or on it, these are only "conventional lines" as seen from the Earth If on the Sun there is *really* a difference between the east and the west as seen from the Earth, then it must be the Earth itself which causes that difference What is east and west or central on the Sun to us on the Earth, would not be so to observers on another planet But consider what the size of an eight-day spot is—47 millionths of the Sun's visible hemisphere, that is to say about 55 millions of square miles, the Earth itself could settle down in such a hole and find room enough to roll a bit Does this preponderance of east over west for the Sun hold.

[The Rev T E R Phillips

THE TAWNY ZONE OF JUPITER

This drawing was made in 1920, March 18, and shows the "belts" and "zones" of the Sun's greatest satellite Jupiter is very elliptical, its equator bulges greatly because of its rapid rotation The broad middle band is the "Equatorial Zone," and normally is of pure white colour, but from time to time it assumes a deep ochreish yellow The zone becomes tawny-coloured about every twelve years and it is suggested that this change in colour may be connected with the solar cycle, since the Sun sends out particles charged electrically causing auroræ on the Earth and perhaps this effect on Jupiter

good only for eight-day spots? For the 12 years, 1889–1901, the writer counted the number of spots coming round the Sun's east limb out of the invisible hemisphere and found them 947, but the number that went from the visible side of the Sun round the west limb into the unseen hemisphere was only 777 That is 170 spots, or 22 per cent of the whole number, seem to have been killed by the Earth Comparing the birth-rate and the mortality tables for the seen and unseen hemispheres of the Sun the writer got the following curious result —

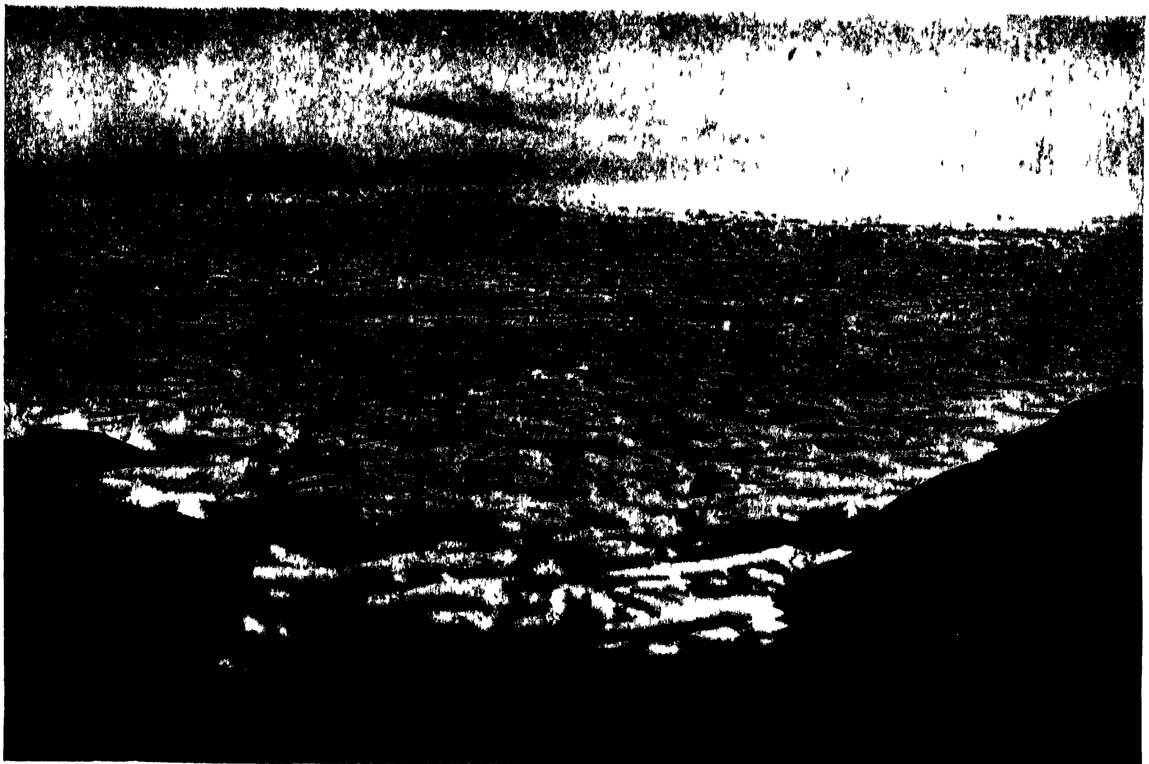
	N hemisphere	S hemisphere	Whole disc
Born on visible hemisphere	171	223	394
Born on invisible hemisphere	258	314	572
Died on visible hemisphere	248	316	564
Died on invisible hemisphere	181	221	402

Thus both north and south indicated that the greater number of spots were born on the unseen hemisphere, but the visible hemisphere proved the graveyard for the majority of spots

But sunspots are not the only features of the Sun There are prominences, these are like great flames, and these too showed that, as a rule, there were more of them visible on the eastern edge of the Sun than on the western As a rule, but not always, for with prominences as with sunspots, it seemed when the Sun's activity died down as if the western flames were slightly more numerous than the eastern

The Earth is so small, and the Sun and its spots and flames are so vast, that it seems absurd to suppose that a body like the Earth could influence structures so much greater Might it not be that sunspots are holes which slant backwards, and if behind them the Sun's surface were heaped up, it seems possible that as the spots came up the eastern slope to the central meridian we should see their front parts unhidden by the faculous clouds, but as they went down the western slope we would see them partly covered up by the faculæ behind them

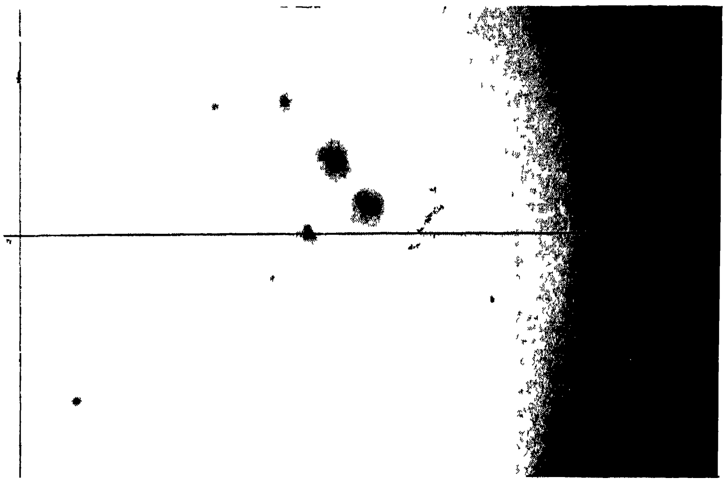
In 1921 E W Maunder tested this suggestion by investigating whether the faculæ themselves showed any preference for the east or the west If they should show no preference then they might well be the cause of the apparent preference of sunspots for the east, since the faculæ lie above the sunspots and tend to lag behind them But for the 42 years examined by E W Maunder the eastern faculæ predominated over the western, slightly but persistently for such parts of the solar cycle as the Sun is most active, during those years when the Sun quieted down the western faculæ were the greater and more numerous This is the same result as is found for the solar flames Now there is nothing to hide the faculæ, and therefore it would seem as if the Earth does exercise a real and sensible influence upon the forces within the Sun It is an influence that is not equally efficient



By permission of] [*The Yerkes Observatory*

LOW LYING FOG CLOUDS AS SEEN FROM MOUNT WILSON

These clouds lie some three or four thousand feet below the great Solar Observatory on Mt Wilson in California, and when present they are used to find how much sunlight is reflected from such cloud This is of importance for comparison with the sunlight reflected from the planet Venus as an indication whether she is covered with cloud or not



[*Greenwich Observatory*

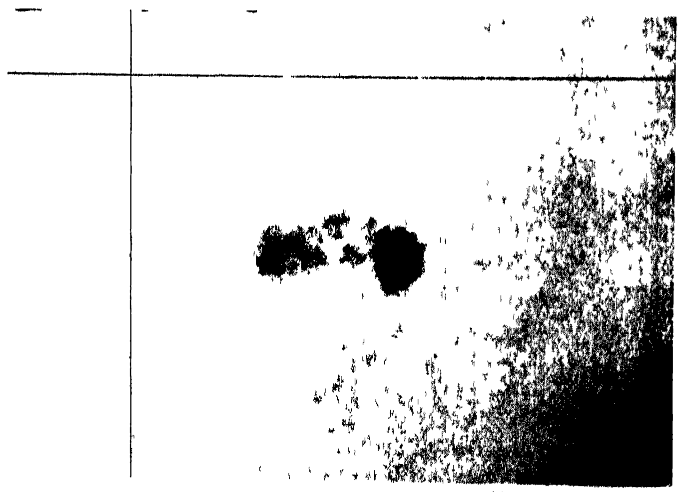
"REGULAR" SUNSPOTS

These sunspots of different sizes are all of the "regular" type, having round black *umbræ* surrounded by round grey penumbræ Note that the Sun's limb is less bright than its centre

at all times, it is most potent when the Sun is active, when the Sun is quiet the Earth's influence dies down, or perhaps even acts in a contrary direction

Spots, faculæ and prominences all keep the law of the 11-year cycle, but they keep it somewhat independently, they attain their maxima and die down, not all at the same times, just as the northern and southern hemispheres do not act synchronically And another feature of the Sun also keeps this law When the Sun's bright disc is wholly covered by the Moon and so is eclipsed, we see round its edge a radiance shining, not a halo or glistening atmosphere such as surrounds a candle flame in a fog, but a structured radiance that is called the Sun's corona (see p 126) When the Sun's activity is at its least the corona seems to consist of two pairs of wings folded more or less symmetrically along the line of its equator, together with coronal plumes at the north and south poles, not unlike some types of auroræ on the Earth At maximum activity, when the sunspots are spread most widely in longitude and latitude, the great wings, or petal-shaped leaves of the corona, spread out in all directions, appearing sometimes even to cover the poles of the Sun, and the broad bases of the petals surround the regions where spots have been and above which the prominences flame But the tips of the petals do not taper to a point, but stretch out into long rod-like rays—beams with parallel edges—to limits beyond what no photograph as yet has been able to trace them All these features are turning, though with unequal rates, with the Sun as it turns on its axis, and we know that the causes which excite them lie within the Sun Can we get any measure of the depths at which these causes lie, from the differences in behaviour?

In 1905 E W Maunder and the writer investigated the solar rotation periods for the two cycles, 1879-1901 We found that the rotation period of the Sun, obtained by Carrington, does not correspond to a latitude of between 10° and 15°, as he supposed, but is given by the separate spot groups of latitude 22½° or by the "recurrent" groups of latitude 20°, in other words, Carrington's period is not that of the mean of all spots, but is considerably larger than that mean



[*Greenwich Observatory*

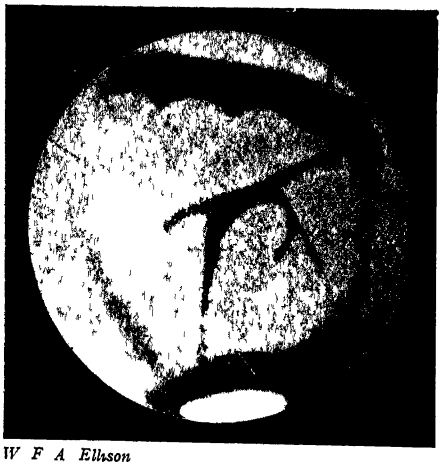
A COMPLEX SUNSPOT STREAM

The leader is "regular", the trailer spot is very complex, in between them there is much grey penumbral matter with small umbræ Note the black umbral trench in the trailer

[G W Ritchey

THE OWL NEBULA

Like many planetary nebulæ, the "Owl" has a bright star placed almost centrally within its circle There is very little doubt that the nebula is closely associated with this star, and it has been suggested that the nebula owes its light to the star's light being either reflected wholly at each point, or re emitted without loss Mr Hubble, of Mt Wilson Observatory, suggests that the star may send forth streams of minute charged particles which excite the nebula electrically as the Sun excites auroræ on the Earth The Owl Nebula is the largest planetary nebula in the Heavens, and lies near the second Pointer Star in the Plough



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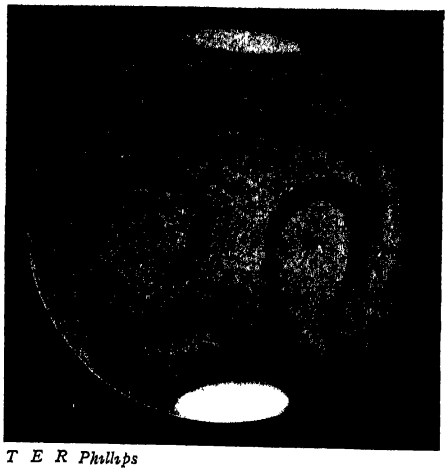

T E R Phillips

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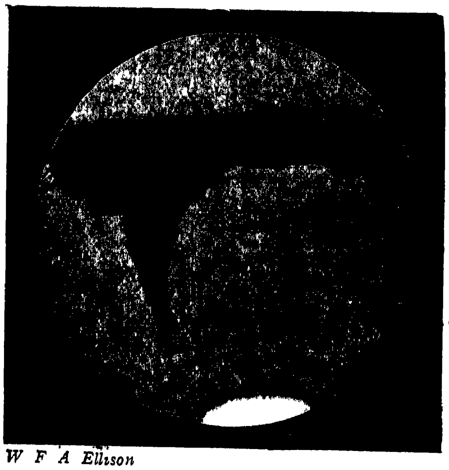

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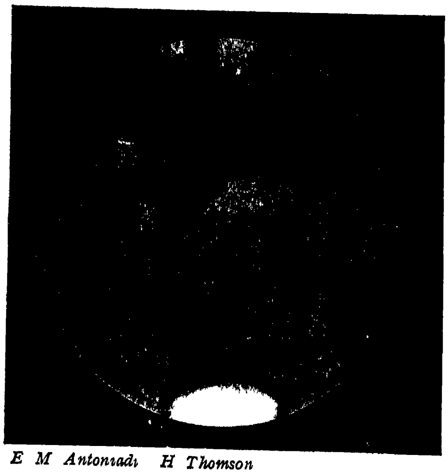
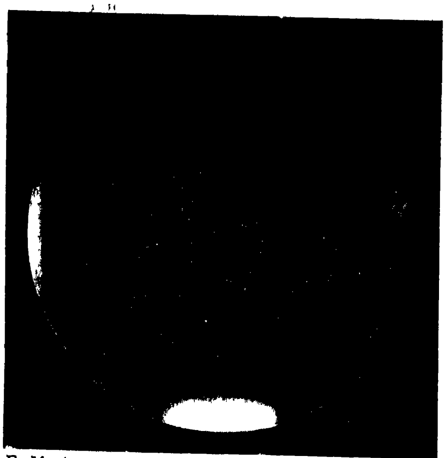


E M Antoniadi H Thomson



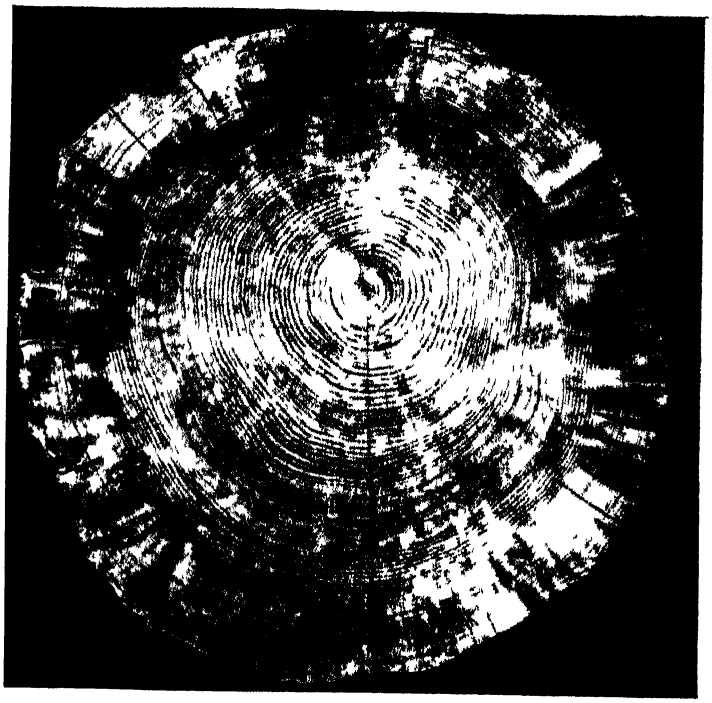
E M Antoniadi] [*British Astronomical Association*

MARS IN 1916

Six views of the planet Mars showing the north polar cap These drawings show different presentations of the north pole of Mars, but do not show its change of size with the Martian seasons, as all were made within a couple of months But in addition to the change in size of the polar cap of Mars with the seasons—just as our northern polar ice melts to some extent in our northern summer—M Eugene Antoniadi has shown that the Martian snows melt more quickly when the Sun has many spots and more slowly when there are no sunspots

We also found that spot groups which have different lengths of life, if discussed separately, give different rotation periods for the Sun There are "short-lived" spot groups lasting for six or seven days, "medium" and "long-lived" (13, 14, or 15 days) and "recurrent" groups, these lasting through more than one apparition, that is for at least three weeks, and perhaps for five or six or even for some months The longer lived the group the slower is the rotation which it gives for the Sun, and we infer that a disturbance causing these slower moving and steady "recurrent" groups lies deeper down in the Sun and approximates more closely to its true rotation period than the shorter-lived and more erratic groups caused by disturbances lying nearer the surface In other words, slowness of mean motion is a criterion of depth for the layer under examination

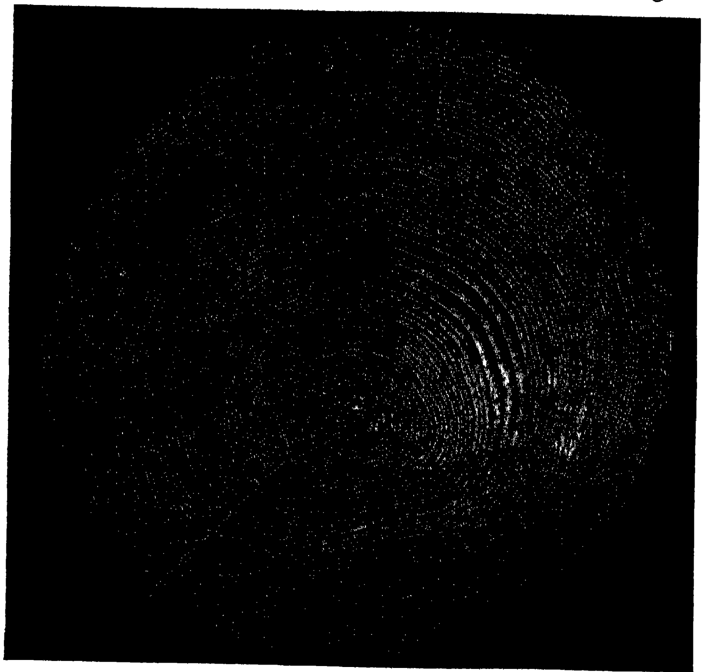
We found also that though the higher the latitude the longer the rotation period of the latitude, yet the shortest mean period is given, not by the equator itself, but slightly to the north of it On the whole the periods in the northern latitudes tend to lengthen more rapidly with distance from the equator than those of the southern, and this phenomenon is found not only in the totality of groups but also in the very long-lived " recurrent " groups For the whole number of groups, short-lived taken with long-lived, we find that the northern hemisphere moves more rapidly than the southern until latitude 20° is passed, after which the southern moves more rapidly, in the case of the deep-seated recurrent groups, treated by themselves, the northern hemisphere is the more rapid until 25° is passed, after which it is slower than the southern



[A E Douglass

THE SOLAR CYCLE AND TREE GROWTH

A section of a Scotch pine of six inches diameter from Ös, Norway It was cut in 1907 and the incomplete outermost ring was grown that year, the innermost ring was 1848 Arrows mark the years of sunspot maxima



[A E Douglass.

THE SOLAR CYCLE AND TREE GROWTH

A log from Dalarue, Sweden, whose outermost ring was grown in 1911 Cycles or pulsations are easily seen in the grouping of tree rings, and can be identified in sections of other trees and with years of many sunspots

If a photograph of the Sun is taken by means of the spectroheliograph in a ray of light from Calcium, so that a picture is got of the Calcium clouds (these are like faculæ, but are not identical with them) they are called Calcium *flocculi* They lie close to the spots but slightly above them, and obscure them in part Like faculæ, flocculi may also be found where no spot is actually visible Professor Philip Fox, the Director of Dearborn Observatory, when at Yerkes measured the periods of rotation for the Calcium flocculi, as has been done for sunspots at Greenwich, and for them he showed that for every corresponding pair of latitude zones, except the first, the southern hemisphere has a slightly greater rotational movement

Combining the results from Mr Fox and the Greenwich observers, we find that for such groups as are

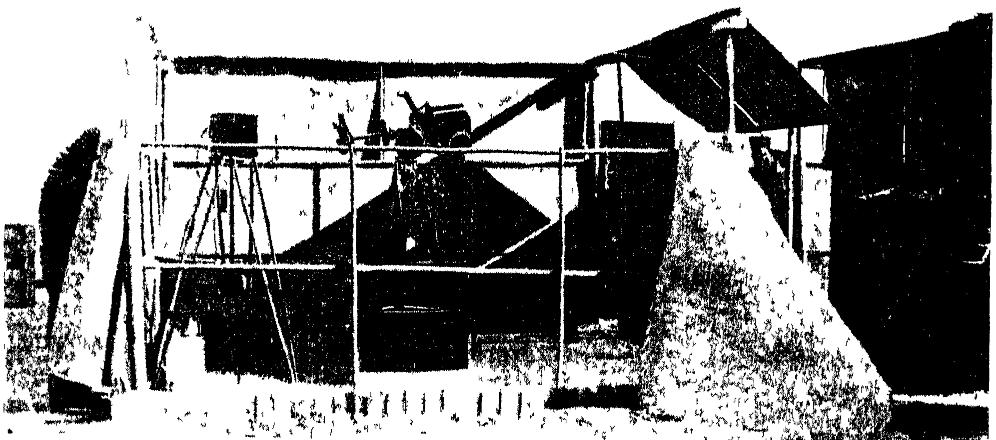
[British Astronomical Association

SUN CRESCENTS DURING A PARTIAL ECLIPSE

During a partial eclipse of the Sun many interesting phenomena are observed The light patches cast by the chinks between leaves of a tree are no longer round If the fingers of the hand are outstretched they appear like a bird's claws

most deeply seated, the northern hemisphere of the Sun rotates more quickly than the southern up to a solar latitude of 25°, for spots at a mean level slightly higher, this northern excess only extends to 20°, whilst for the high flocculi the reverse holds good, and for all solar latitudes beyond 5° the southern hemisphere has the quicker motion We thus infer a state of strain, not only between the southern and northern solar hemispheres, but also between the higher and lower strata in those hemispheres

Dr Bauer, the Chief of Division of Terrestrial Magnetism in the United States, has said — "Modern researches would indicate that the chief source of the Earth's magnetism is not to be referred to permanently magnetised substances, but doubtless to a system of electric currents embedded deep within the interior of the Earth and connected in some manner with the Earth's rotation" May we look therefore to find evidences of magnetism in the Sun, whose various layers rotate in such differing fashion?



[British Astronomical Association

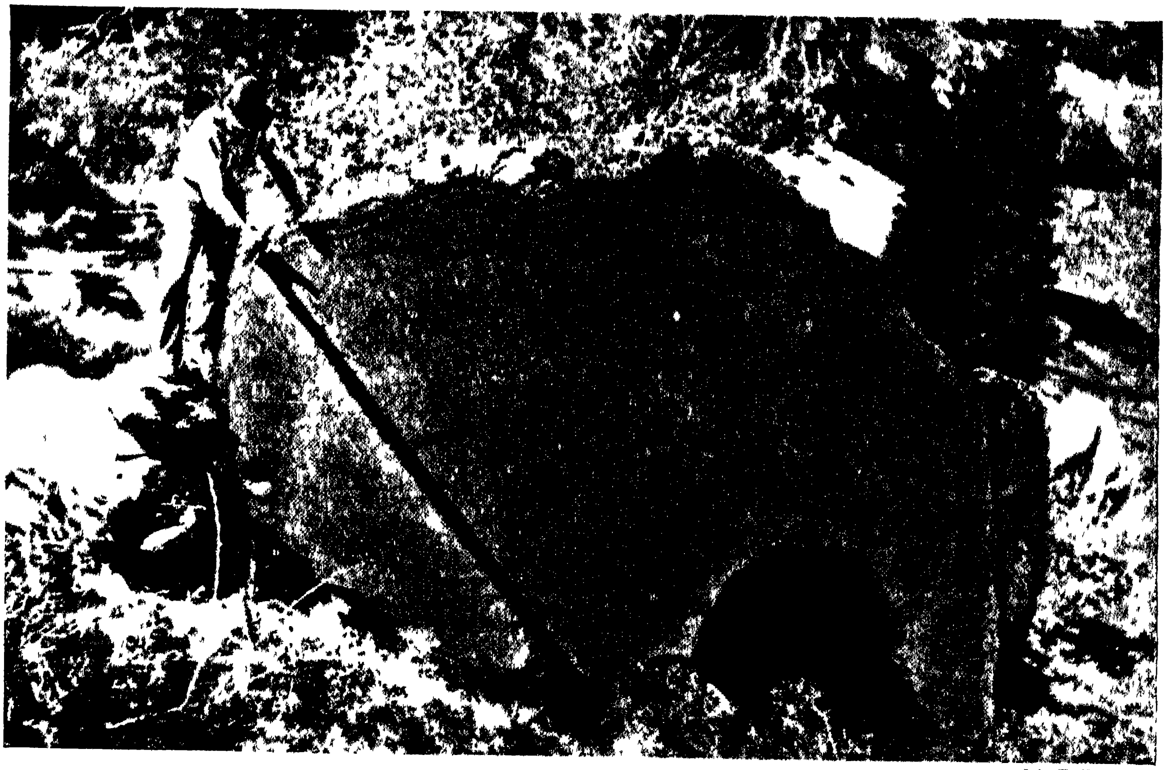
MRS MAUNDERS' OBSERVING HUT IN INDIA

In the Solar eclipse expedition of 1898 to India, the huts housing the telescopes were made of bamboo matting, and when the eclipse began the matting was stripped off the roof The chinks in the matting showed on the floor as crescent shaped patches of light

[A E Douglass

THE SITE OF THE 3,200-YEAR-OLD TREE

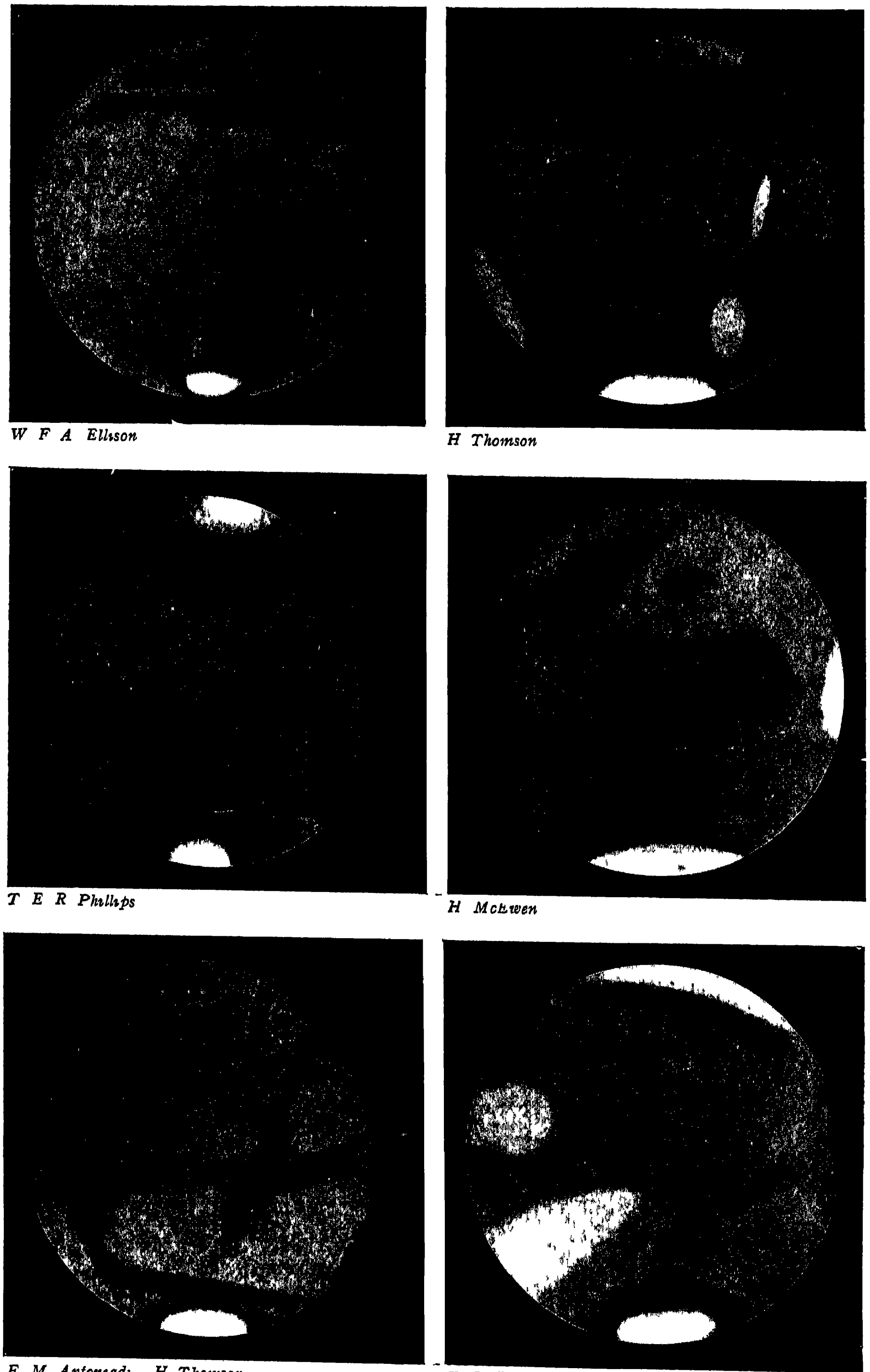
Professor A E Douglass examines sections of trees, since the size of the annual ring is an indication of the annual rainfall This is the site whence was cut down the oldest Sequoia, aged 3,200 years By this means Professor Douglass can carry back the rainfall records and also, perhaps, the solar activity



[A E Douglass

A TREE AGED 2,800 YEARS

Cutting a sample from the end of a log which had grown for 2,800 years The tree had fallen about six years earlier Professor Douglass hopes to be able to test sections of fossil trees also, and so gain knowledge both of the rainfall on the Earth and of the spottedness of the Sun for thousands of years



W F A Ellison — *H Thomson* — *T E R Phillips* — *H McEwen* — *E M Antoniadi H Thomson* — *T E R Phillips*] [*British Astronomical Association*

MARS IN 1916

The planet Mars resembles the Earth in having white polar caps that resemble snow and are probably hoar frost Like the Earth it turns in twenty-four hours very nearly Its atmosphere is very rare and very transparent, so that the features on its surface can at most times be clearly recognised Thus, in the first four drawings there is a very dark patch bordering on the north polar cap which has been given the name of the Acidalium Sea

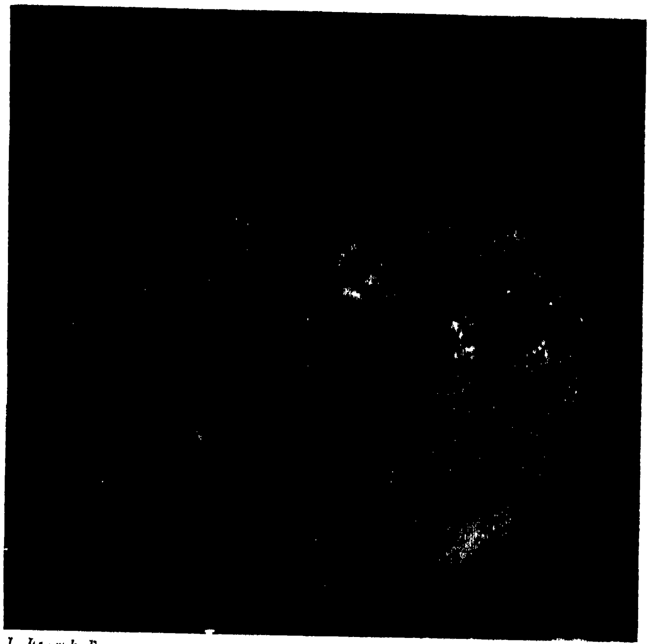
In the waning years of the solar cycle 1901–1913, Professor G E Hale, of the Mount Wilson Observatory in California, found that about 60 per cent of all sunspots are twin groups, the single or multiple members of which are magnetically dissimilar, also in that cycle (the one preceding the current cycle) the "leaders" of sunspot streams in the northern hemisphere of the Sun were of *minus* sign (corresponding to the N magnetic pole of the Earth), and the "trailers" of these same groups were of *plus* sign, for streams in the Sun's southern hemisphere, the "leaders" were of *plus* sign, and the "trailers" of *minus* sign That is to say, in the case of such "bi-polar" groups the magnetic polarity of the two chief members is reversed for opposite sides of the solar equator

Then a strange thing occurred In 1912, just as dead minimum set in, there was a sudden

reversal of the magnetic polarity—the "leader" spots of a stream in the northern hemisphere became of *plus* sign, and of the southern hemisphere became of *minus* sign, the northern and southern hemispheres changed over as regards the quality of their magnetism It was as if the cyclones and tornadoes north of the Earth's equator were suddenly to whirl clockwise instead of counter-clockwise The Sun has been found to have a magnetic axis, and its inclination to the solar axis of rotation and its period are known The Earth and the Sun, rotating in the same direction, are magnets of the same polarity, with magnetic axes which fail to coincide with their rotation axes

This reversal of polarity in 1912 supplies another indication that the cause of the sunspot cycle has its seat within the Sun We do not know if it will again reverse at the approaching minimum It may be worth while to point out that in this last cycle now drawing to a close, the northern hemisphere has proved the more active, for several previous cycles the southern was steadily the stronger It is possible that the relative activity of the north and south may depend on their magnetic signs But this suggestion cannot be established or proved erroneous for several years to come

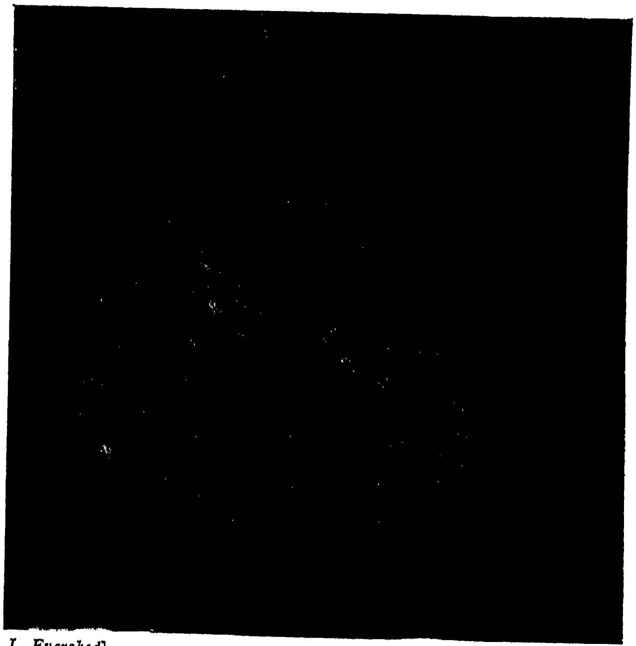
If a photograph of the Sun is taken in the spectroheliograph in $H\alpha$ light, *i e*, the light of the red line of hydrogen, a picture is got of hydrogen flocculi, and the examples reproduced are those obtained by Mr Evershed at Kodaikanal in India On the series are seen sunspots, hydrogen flocculi, and long curved dark markings due to absorption by hydrogen, and this hydrogen is seen on those pictures taken in 1919, May 27–29, as a great prominence, the famous one seen on the eclipse photographs of that year These features alter their positions and shapes from day to day, on May 11 the dark absorption marking forms a great semicircle, partly in the northern hemisphere, partly in the



J Evershed] [*Royal Astronomical Society*

THE SUN IN HYDROGEN LIGHT

A photograph of the Sun taken by means of the spectroscope in hydrogen light and showing dark markings which are due to absorption by hydrogen vapour Note that these dark markings form a very broken circle

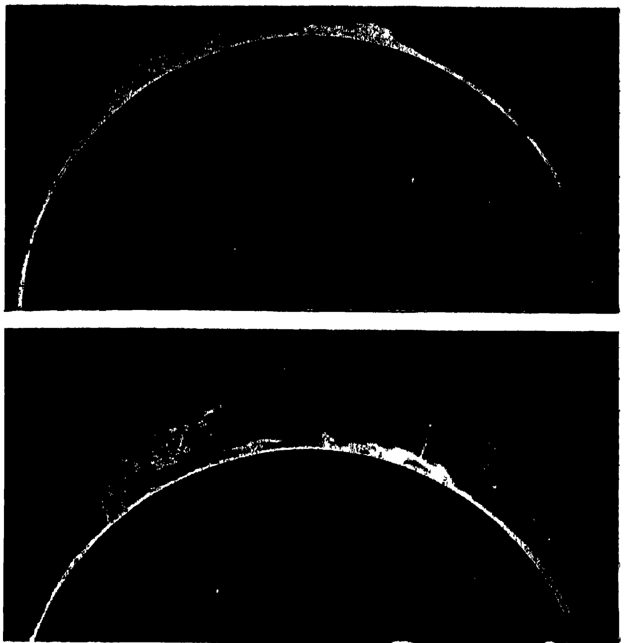


J Evershed] [*Royal Astronomical Society*

THE SUN IN HYDROGEN LIGHT

This photograph was taken two days earlier than the upper one and shows the dark hydrogen markings near the eastern edge of the Sun Note the light hydrogen flocculi lying in broken bands across the Sun's disc

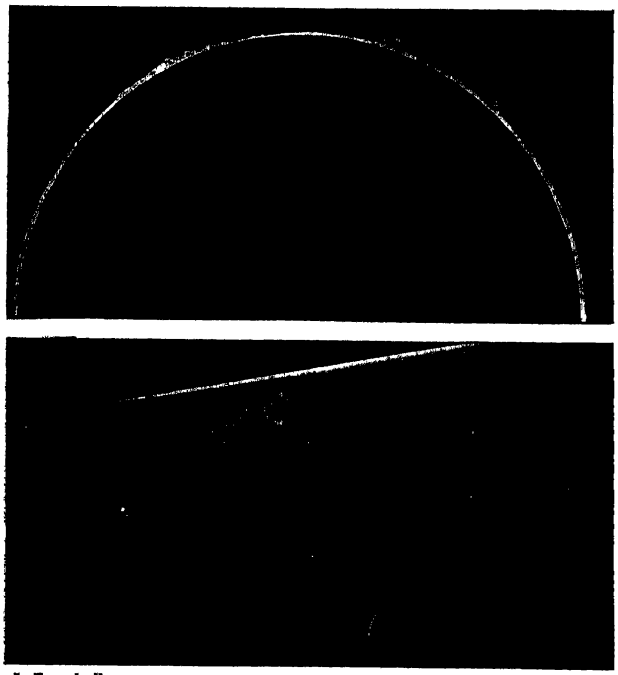
southern, and about the middle of its curve is a large sunspot with bright hydrogen flocculi attached to it Mr Evershed computes that these absorption markings were lying about 30″ higher than the spot, but both spot and absorption prominence were turning through 14° 28 a day—that is almost exactly the amount found by E W Maunder and the writer for the "recurrent" groups, those whose exciting cause lies deepest in the Sun Mr Evershed says that these dark markings often appear to "form the outer boundaries of the regions of sunspot disturbance, their curved linear forms bending round the preceding side of a sunspot group and trailing eastwards on either side, as though the spots were surging through a liquid sea and causing a diverging wave on either side It is difficult to avoid the conclusion that sunspots, flocculi and prominences are all manifestations of the same disturbance emanating probably from the interior of the Sun"



J Evershed] [*Royal Astronomical Society*

THE GREAT ECLIPSE PROMINENCE OF 1919

During the eclipse of the Sun of May 29, 1919, a very fine prominence was seen on the Sun's eastern edge This was a long lived prominence and was photographed by the spectroheliograph for several days before and after the eclipse



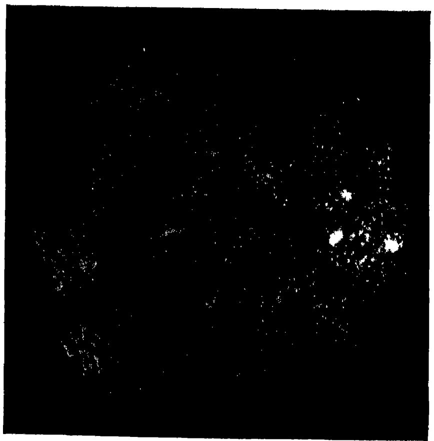
J Evershed] [*Royal Astronomical Society*

THE ECLIPSE PROMINENCE ON THE SUN'S DISC AND LIMB

Prominences are closely connected if not identical with the dark absorption markings due to hydrogen This pair of photographs shows the great prominence on the Sun's west limb on May 16, and on the Sun's disc on May 11, 1919

In a total eclipse we can see not the Sun itself but its surroundings, and here again we find such influences proceeding from the Sun and building up the structure of the corona in obedience to them In the SSE quarter of the eclipse of 1871, December 12, a leaf-like group rises above a bright semi-circular arc, and much fainter arcs can be discerned rising above the lowest one, and above these the sides of the coronal structure are curved as if they would meet Similarly in the eclipse of 1898 in India, such leaf-like curves—"glass cases" as they have been familiarly described—were seen in photographs of the lower corona, and on some small scale photographs, taken by the writer for the purpose of obtaining the outer corona, these curves were found to taper as if tending towards an apex, but instead of reaching a final point, appeared to be blown out and driven away in a straight line into space The longest beam there photographed was traced for at least six million miles

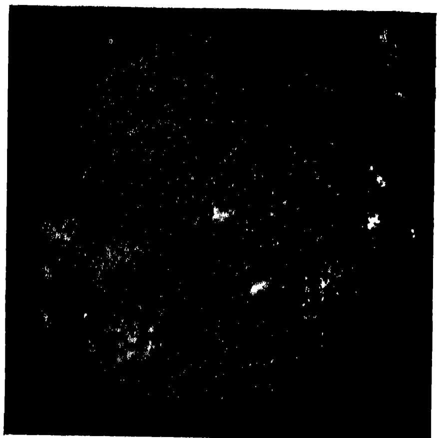
We cannot ever see these various features



Prof Philip Fox] [*Yerkes Observatory*

CALCIUM SPECTROHELIOGRAMS OF THE SUN

Taken on August 27, 1908 The bright patches are calcium clouds, the black points are sunspots almost hidden by the calcium, and there are small calcium clouds all over the Sun



Prof Philip Fox] [*Yerkes Observatory*

CALCIUM SPECTROHELIOGRAMS OF THE SUN

Taken on August 28, 1908 Note how all the calcium markings and the sunspots have moved towards the right hand The two biggest calcium clouds and the enclosed sunspots are almost in the same longitude but in different hemispheres

of the Sun in their relative positions all together, yet we can judge with probability that the broad bases of the coronal wings are outlined roughly by the dark absorption markings, and inside these boundaries the various streams of sunspots, the clouds of hydrogen and calcium, the flames of metals and hydrogen, all respond to the deep underlying disturbance Remembering the facts brought forward by Professor Hale that the "leader" and "trailer" of a stream in one hemisphere are of different polarities, as well as the leaders of streams in different hemispheres, we can understand how the same disturbed area may feed the coronal wings with particles of different signs, which by their mutual attraction give rise to the rod-like beams that issue from it When these parcels of electric particles, charged with different signs, cross the space that separates the Sun from a planet—the Earth or Jupiter—what happens to indicate their arrival ?

First, the Earth We have long known that a magnetic needle will point nearly due north and south if undisturbed But it does not remain undisturbed for long, for day by day from about nine in the morning till about two in the afternoon there is a feeble swing of the magnet to the west, and during the remaining hours it creeps back But the extent of the swing is greater in summer than in winter, greater at times when there are many spots on the Sun than when there are few Terrestrial magnetism conforms to the 11-year solar cycle On the Sun every now and then—we cannot foretell it—a monster spot breaks out and passes across the disc into the

Prof Philip Fox] [*Yerkes Observatory*

CALCIUM SPECTROHELIOGRAMS OF THE SUN

Taken on September 1, 1908 Note that the two great calcium patches in the Sun's northern and southern hemispheres have moved past the central meridian into the western hemisphere

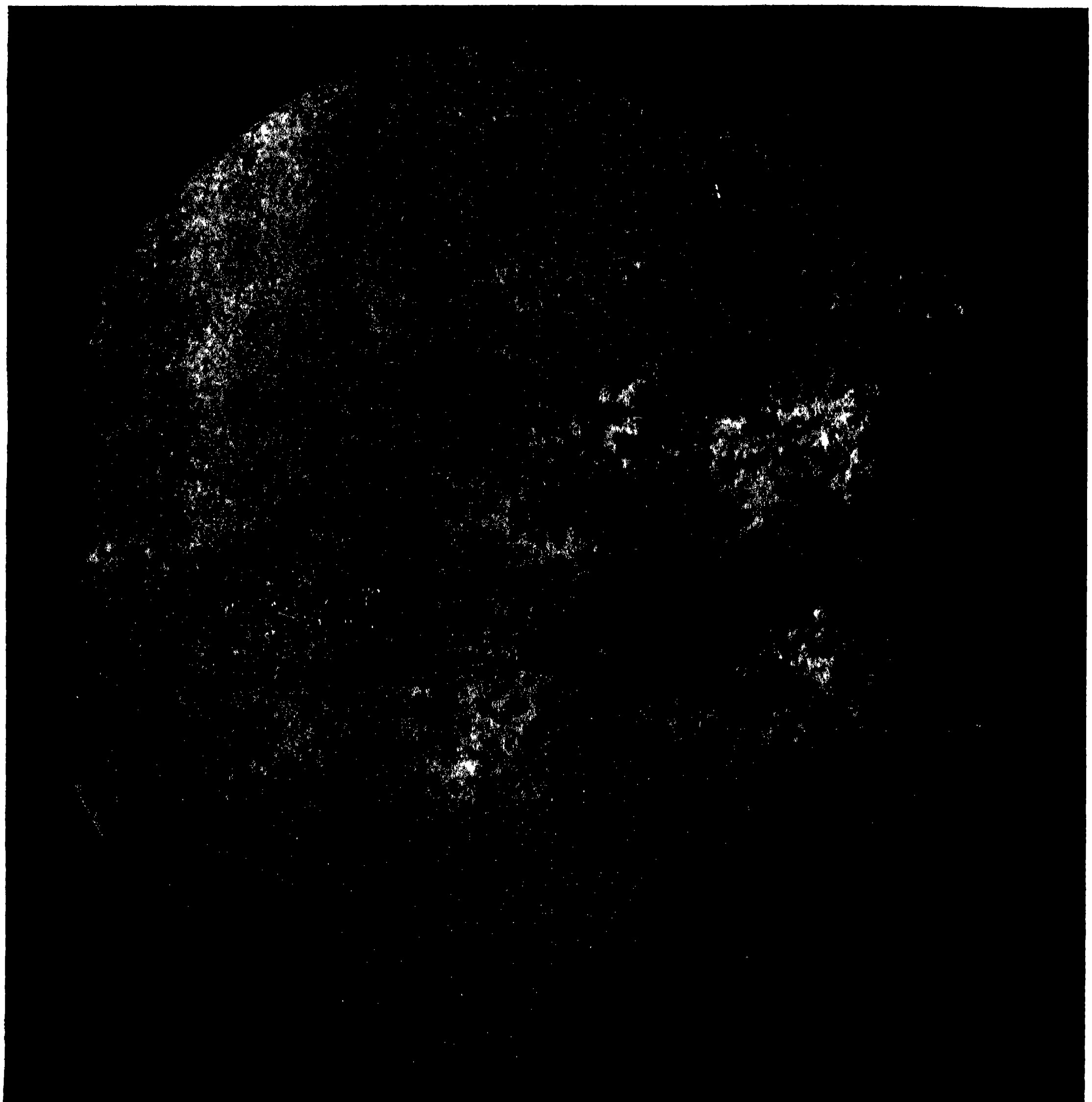
Prof Philip Fox] [*Royal Astronomical Society*

CALCIUM SPECTROHELIOGRAMS OF THE SUN

Taken September 2, 1908 The Sun has turned the parallel calcium bands farther to the west, the eastern hemisphere of the Sun is nearly devoid of them The northern spots are almost hidden

unseen hemisphere, and may cross and recross it several times, we know it to be the same spot by its solar longitude and latitude On the Earth every now and then, without warning, the magnetic needle becomes violently agitated, we have a magnetic storm, which lasts for some hours or a day or two, and dies down, and the needle swings again with a gentle throbbing, to and fro, until another unexpected storm agitates it afresh Are these unexpected events connected in any way? They occur sometimes together and sometimes quite separately We can recognise a spot when it returns to the visible hemsiphere, can we recognise a magnetic storm again?

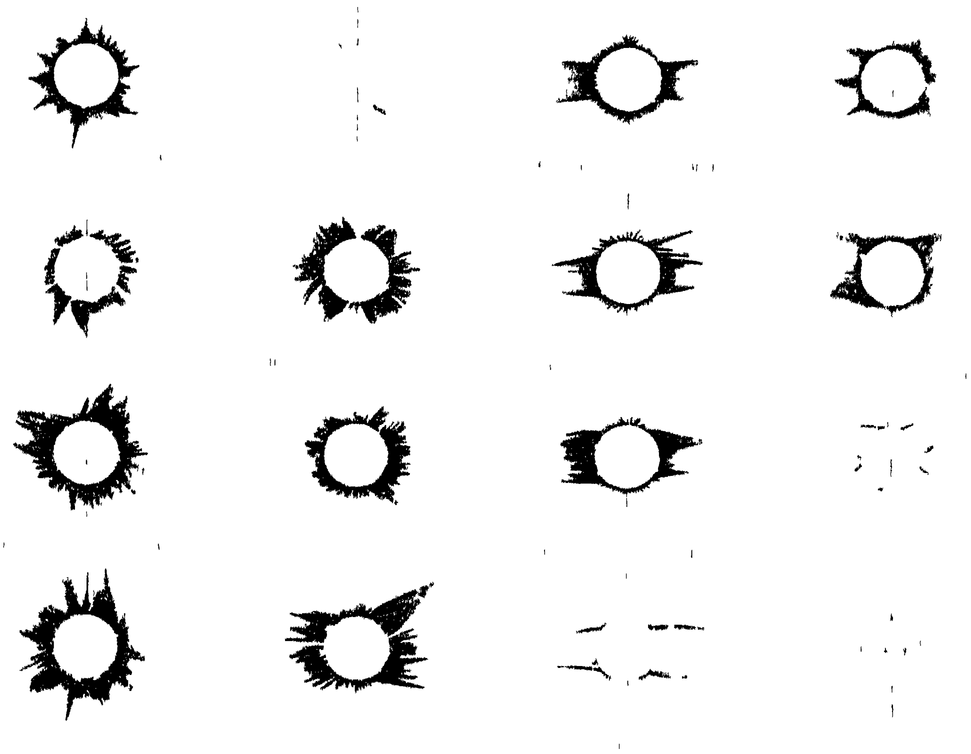
We can recognise it, and in just the same way as with sunspots, as E W Maunder has shown



Prof Philip Fox] [*Royal Astronomical Society*

CALCIUM MARKINGS ON THE SUN

Professor Fox found that he was able to identify some of the small calcium markings on the photographs of the Sun taken in calcium light, and that he could follow these sometimes for four, five or six days Accordingly he measured the positions and areas of these markings for each day and so obtained their solar longitude and latitude, as the Greenwich observers obtain the solar longitude and latitude of sunspots From this Professor Fox was able to conclude that Calcium Flocculi gave a rotation period for the Sun not very different from sunspots, though they lie at a higher level than the sunspots



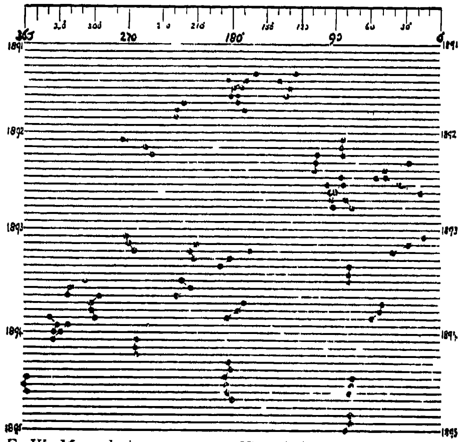
[British Astronomical Association

TYPES OF SOLAR CORONÆ

We find that the corona varies with the solar cycle When there are many spots on the Sun the corona is rayed like a star, when the Sun is quiet and there are no spots upon it then the great coronal streamers seem to fold themselves about the Sun's equator In the picture the first column shows the corona at solar maximum, the second column, when the Sun's activity is on the decline, the third, when it is at minimum and the fourth, when it has reawakened Note especially the maximum eclipse of 1893 and the minimum of 1878 and 1889

The time between the return of the spot to the same place is the apparent time that it takes the Sun to turn on its axis, and that is the time that occurs over and over again as the interval between successive magnetic storms In the two diagrams (page 146 top), in each case the length of the parallel lines represents one rotation of the Sun, the dots give, in that rotation, the longitude of the centre of the Sun's disc—in the one case of "recurrent" groups, whether they were north or south, in the other case for the time of beginning of a magnetic storm The two diagrams are not for the same dates, so there is no actual connection between the two sets of phenomena, but it is obvious that if there are no labels attached it would not be possible to say which related to sunspots and which to magnetic storms, their motions and the variations of their motions are of the same order On a particular region of the Sun some commotion occurs sunspots, faculæ, flocculi, prominences, are found, above the disturbed area a great petal-like streamer of corona arises, and its apex drawn out into a rod-like ray, containing parcels of charged particles, which extend from the Sun to distances which may be expressed in scores or hundreds of millions of miles When those parcels of charged particles overtake and strike that part of the Earth where the Sun is setting (since the Sun turns on its axis in the same direction as that in which the Earth is revolving in its orbit), a disturbance, more or less violent, occurs of the Earth's magnetism

Such disturbances may be visible as auroræ on the Earth, and in the 70 years' dearth of sunspots,

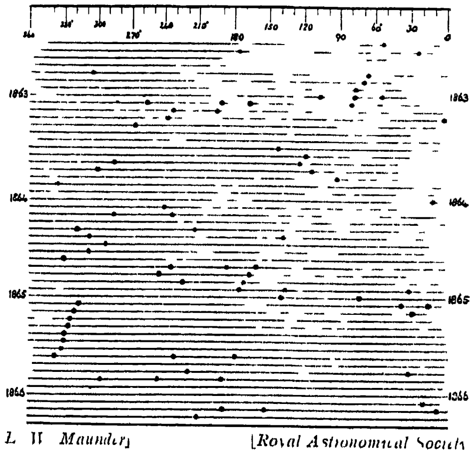


F W Maunder] [Royal Astronomical Society

SUNSPOTS AND MAGNETIC STORMS

The horizontal lines each represent a rotation of the Sun marked out in longitude by the scale at the top The linked dots are long lived sunspots whether north or south

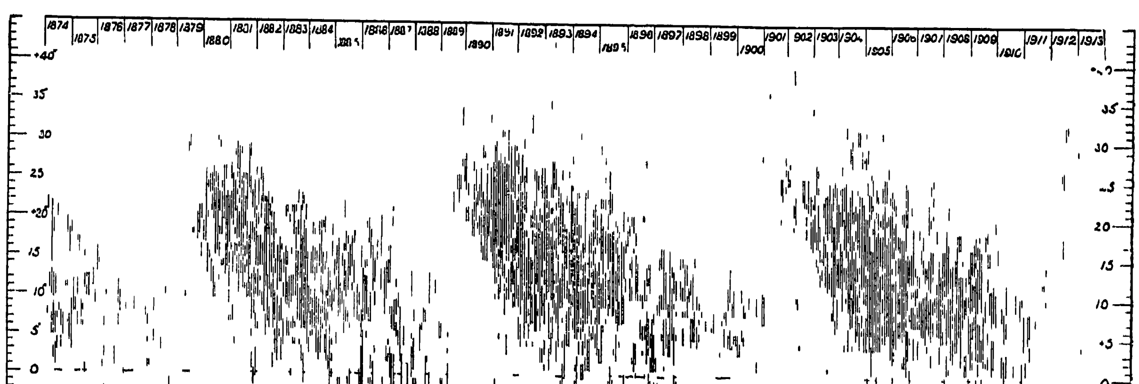
auroræ were lacking Auroræ as well as magnetic storms obey the law of the Sun's rotation, and this could not be so if the influence that brings about our magnetic storms and auroræ proceeded equally from every part of the solar surface and was radiated from it equally in all directions It follows that both magnetic storms and auroræ are brought about by an influence which arises from restricted areas of the Sun's surface, and is discharged from such areas in restricted directions Further, Mr Gavin Burns has tabulated the records of auroræ of the years **1916–1919**, in accordance with the solar rotation, and his tables show



L W Maunder] [Royal Astronomical Society

SUNSPOTS AND MAGNETIC STORMS

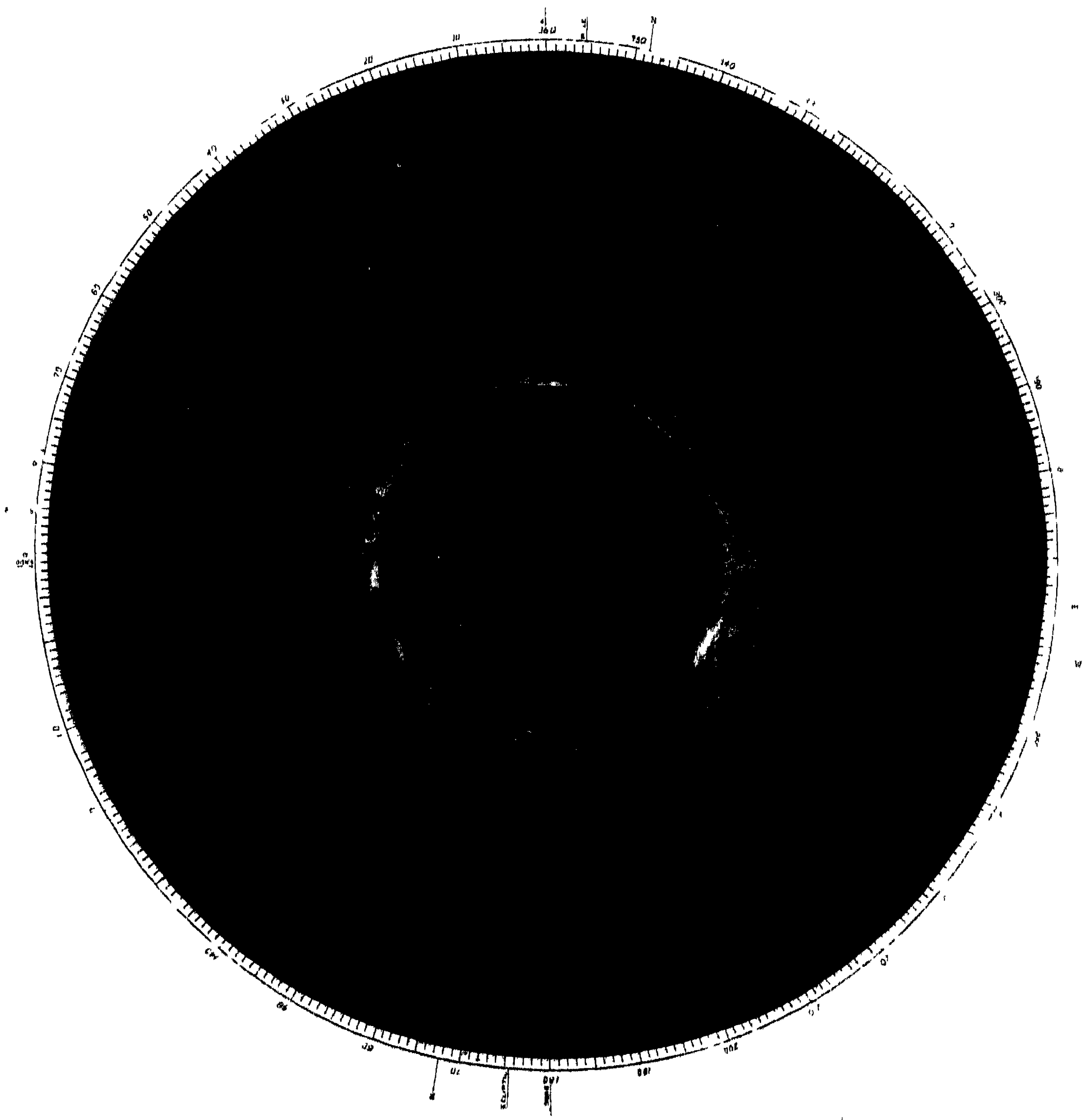
The horizontal lines and the scale of longitudes are the same as for the preceding picture, but the dots now represent the beginnings of magnetic storms on the Earth



E W Maunder [Royal Astronomical Society

THE BUTTERFLY DIAGRAM

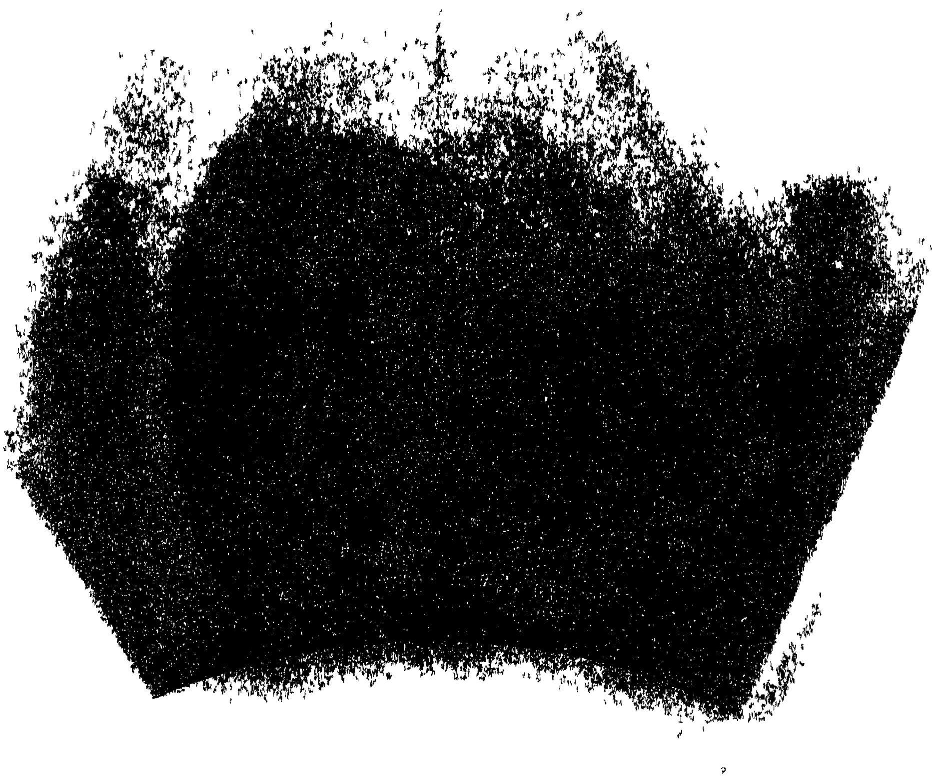
Each vertical line represents a sunspot whether great or small occurring in the rotation of the Sun and in the latitude north or south Note that each solar cycle is marked off from the one before it and the one after it without any possibility of doubt Note that the south seems stronger than the north



[Royal Astronomical Society]

THE CORONA OF 1871, DECEMBER 12

This is a drawing made by Mr A C Ranyard and Mr W H Wesley from the photographs taken by Lord Lindsay's expedition to Baikul to observe the eclipse of 1871 Note the arching prominences in the lower left hand quarter of the eclipsed Sun and the series of arches above them formed by coronal material Note the bright loop in the east north east quadrant Note the black straight rift in the west north west quadrant The coronal streamers have almost masked the polar rays but those at the Sun's north pole are distinguishable Note the prominences near both the north and south poles of the Sun



A CORONAL STREAMER [Royal Astronomical Society

This is an enlargement of the north-west coronal streamer of the eclipse of the Sun of 1871, December 12 The drawing is in negative, for the artist, Mr W H Wesley, drew the bright parts dark as on the original photographs The white streak on the right side of the picture is the very black streak seen in the west north-west quadrant of the preceding picture This streak is probably due to absorbing matter and its straightness is in sharp contrast to the natural curve of the corona seen on the left side, the leaf like structure arching over an active region on the Sun

that the greatest displays synchronised with the return of certain special meridians to the centre of the Sun's disc; other meridians on the Sun appear to leave our atmosphere quite undisturbed. The Sun is structured, not only as between the northern and southern hemispheres and as between different latitudes, but, as regards its emanations, as between some of its longitudes also.

Besides this influence on magnetic storms and auroræ, in two other cases there are indications that the state of the Sun's interior influences the conditions on the Earth. In the first case, in 1909, E. W. Maunder showed that the cyclones of the Indian Ocean present several striking instances of the recurrence of the cyclone at the interval of the solar rotation as it appears from the Earth. Thus cyclones occurred on the following dates: 1865 December 8, 1866 January 6, February 2, March 3, and March 30, and it is improbable that such a sequence should be wholly accidental, especially as there were no other cyclones catalogued for the half year, 1865 October to 1866 March.

The second case is that in which astronomy, meteorology, and botany, join. Professor A. E. Douglass desired to understand the variations of the Sun through their correlations with climatic phenomena. As the science of meteorology is still comparatively new, he sought botanical aid in order to extend his knowledge of weather changes over hundreds and even thousands of years by

[A. S. D. Maunder

THE LONG CORONAL RAY

This drawing was made by Mr. W. H. Wesley from the small scale coronal photograph taken by the writer in India in the eclipse of 1898. The coronal streamer in the south-west quadrant is petal like at its base, but the tip of the petal extends outwards in a rod-like ray for at least six millions of miles.

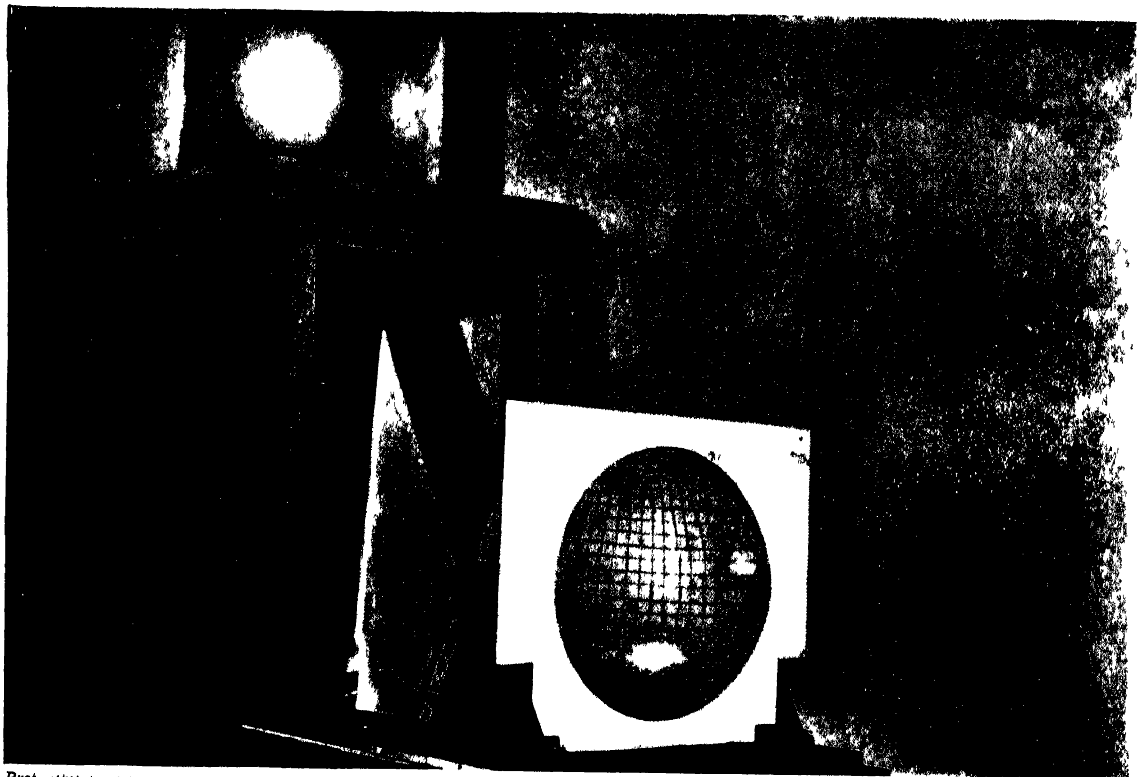
making use of the dependence of the annual rings of trees in dry climates on the annual rainfall. He investigated chiefly the pines and sequoias of northern Arizona, and his argument was that the tree-rings measured the growth and the growth depended roughly on the amount of moisture. Only the yellow pines and the sequoias extend back beyond the first telescopic observations of sunspots, and from the yellow pines he finds an 11.4-year cycle, and in addition, for 60 years following the year 1660 (corresponding to the 70 years' dearth of spots) the curve flattens out. The sequoias also show this flattening but for the years 1670–1727. It will be noted that in the case of pines and sequoias both, there is a lag before the long minimum of 1645–1715 takes effect. In certain wet climates, where trees give a good record of the solar cycle, we find that the maximum ring growth is three years in advance of the solar maximum.

Professor Douglass says: "The yellow pines of Arizona give evidence that 500 years ago the cycle was operating very much as now. The sequoias, if correctly interpreted, already carry the history

back some 3,000 years, and beyond that fossil trees may stretch the time covered, in part at least, into millions of years"

Leaving the Earth and its meteorology, the next planet beyond is Mars, and in 1916 E M Antoniadi (the most skilled and careful areographer of the present generation) detected an agreement between the erratic melting of the snow caps on Mars and the solar cycle Out of 21 cases observed of the melting between 1862 and 1914, 17 are favourable to the agreement in question

The solar cycle in tree-rings and in the melting of the snow caps on Mars may be due rather to the relation of solar heat to solar activity than to the action of parcels of charged particles sent out by the Sun But in the case of the next planet, Jupiter, the effects produced are not a case of much or little heat, but of changes, in my opinion, excited by emanations of such particles from the Sun

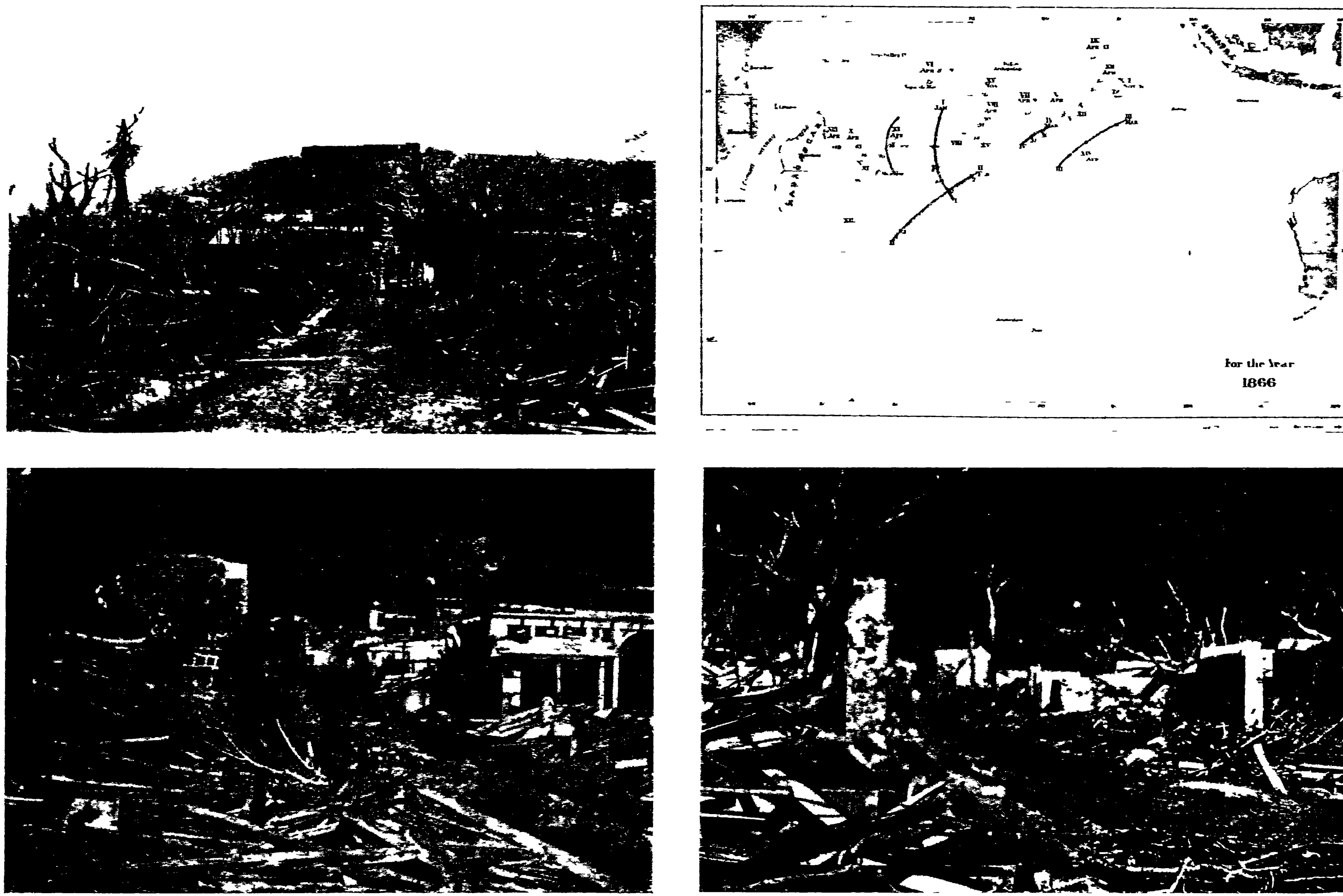


Prof Philip Fox] [*Yerkes Observatory*

THE YERKES WAY OF MEASURING FLOCCULI

At Greenwich, solar photographs are measured accurately in a micrometer so as to get the latitudes and longitudes of sunspots Calcium flocculi are immense shapeless clouds and it is not possible to measure them in this way, and accordingly, at Yerkes, the spectroheliograms are projected neatly upon a ruled globe as shown

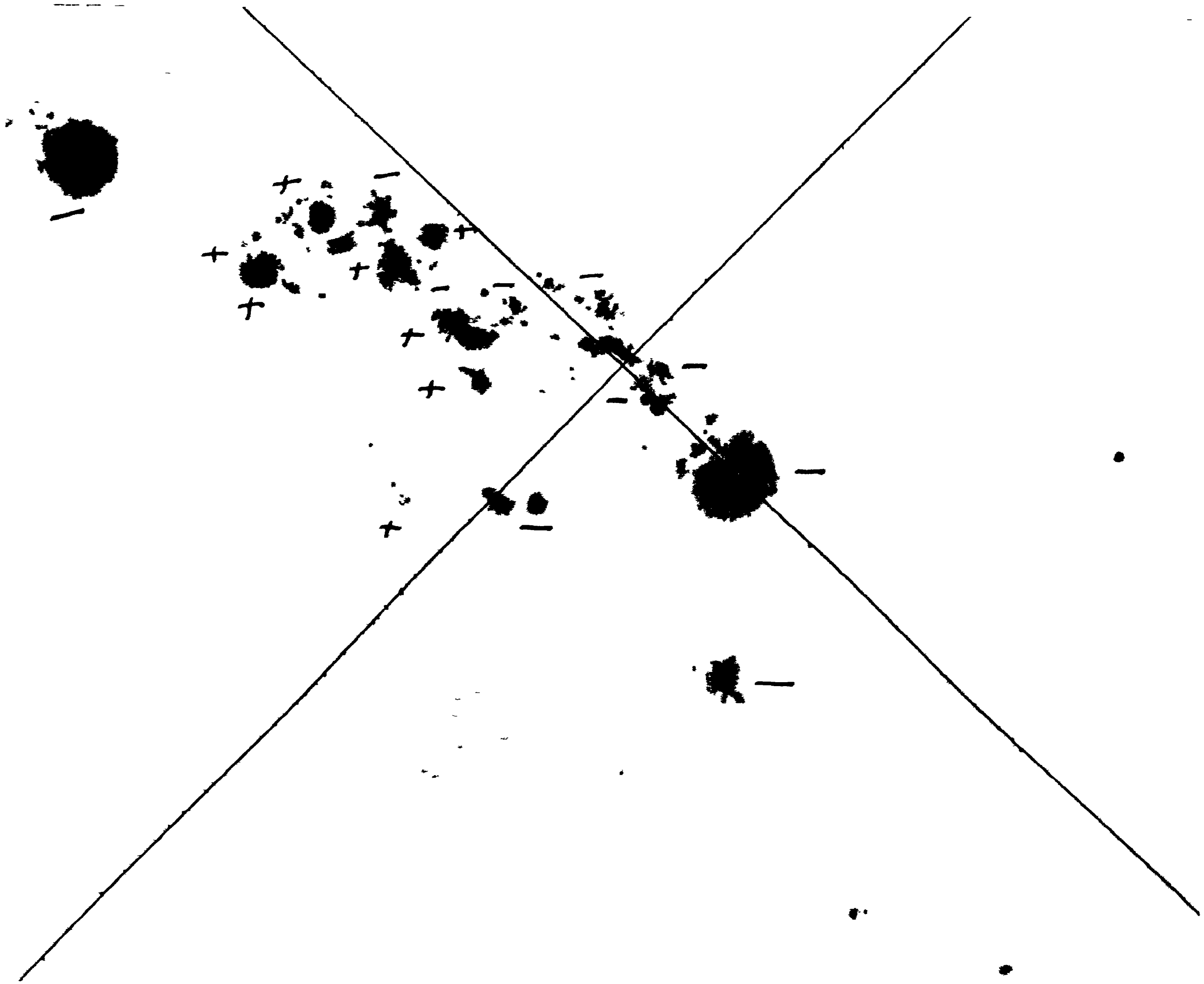
Mr Stanley Williams pointed out in 1899 that the north and south equatorial Belts are given to an interchange of their colouring When the north equatorial Belt is intensely red the south equatorial Belt is not only devoid of red, but even bluish, later, in two or three years, both Belts are equally reddish, then again in two or three years' time the south is intensely red and the north bluish, and so on In the intermediate stages when both are reddish the equatorial Zone may take on a "tawny" hue (actually when the south equatorial Belt is changing from red to very red, and the north from red to blue, but not conversely), and in 1920 Mr Williams investigated this colour change also For the colour cycle in the Belts he gets 12 18 years, and for the Zone 11 95 years, but the interval between one maximum and the next may vary by one or more years, just as the solar cycle does Mr Williams attributes these changes to a "seasonal" effect due to Jupiter's revolution



[E W Maunder

CYCLONE TRACKS IN THE INDIAN OCEAN

Certain regions, usually not far from the equator, on the Earth are subject to very violent storms, called typhoons, tornadoes, or cyclones. The map shows a series of tracks of such cyclones in the Indian Ocean between Madagascar and Sumatra. In many cases the storms follow each other at intervals twenty-eight days apart, roughly at times when the Sun turns the same region to the Earth. The other three pictures show the effect on Port Louis, the harbour town of the Mauritius, caused by the great cyclone in April 1892, a year of great sunspot activity. Port Louis was badly damaged.



(Greenwich Observatory)

A GREAT BI-POLAR STREAM

Prof G E Hale, of Mt Wilson Observatory, California, has made a study of magnetic fields on the Sun and has found that the leaders and trailers of sunspot streams are of different magnetic sign, and that the leaders of spots in different solar hemispheres are also of different magnetic sign In this great sunspot group, photographed at Greenwich Observatory, it will be seen that the leading spots are of *minus* sign and the following spots of *plus* sign, the intermediate spots are of mingled polarity Note the great regular spot following the stream This is of *minus* sign also and shows that it also is the leader of a group

round the Sun in 11·86 years. But Jupiter's axis is nearly perpendicular to this orbit, so that no true seasonal effect can be produced on his equatorial Zone and Belts, and though the eccentricity of his orbit is three times that of the Earth's, the general change in heat from perihelion to aphelion should not affect differently the north and south equatorial Belts, seeing that they are equally presented to it.

In the case of the Sun we saw from "the Butterfly Diagram" that the cause of its changes must come from within, so on Jupiter the cause of the changes in his equatorial Belts must lie within him; it cannot be any general influence impressed from without. If the changes on Jupiter are at all related to the Sun then they must be brought about by solar influences which act differently on Jupiter's northern and southern hemispheres, because these are different the one from the other.

In December 1922, E. Hubble, of the Mount Wilson Observatory, California, published his investigation of the sources of illumination of diffuse nebulæ which had bright stars involved in them. He found that the stars were the cause of the illumination of the nebulæ; that these re-emit or reflect exactly the same amount of light as the stars shed upon them at any point, and as a rule light of the same quality. He also found in his study of nebulæ of more definite form surrounding central stars

From "Knowledge"] [*By permission of the Astronomer Royal*

GREENWICH OBSERVATORY FIFTY YEARS AGO

On the right is Flamsteed House, the original observatory built by Sir Christopher Wren. On its roof are seen the wind registers and time ball. In the background is seen the transit house, where is the fundamental telescope of the Greenwich Observatory. The dome, like a gasometer, housed the largest instrument then at Greenwich, a 12¾ inch refractor.

known as "planetary nebulæ" from their disc-like appearance bearing rough resemblance to planets—that their luminosity is apparently excited by the radiation from those central stars or streams of electrically charged particles. It would not be surprising therefore if we should find that such emanations from the Sun—which cause auroræ and magnetic storms upon the Earth—also produce effects upon Jupiter, and become evident to us there in changes of colour.

THE ATMOSPHERE OF THE SUN

BY C P BUTLER, A R C Sc, F R P S, F R A S

To the observer at ordinary times, without optical aid, the Sun appears only as a brilliant disc, which may at intervals exhibit dark markings known as sunspots Occasionally the Moon, coming in between the Earth and the Sun, completely obliterates the disc, and it is during such Total Solar Eclipses that indications of the presence of something outside the Sun's edge must have been presented in past ages to all who were sufficiently interested to observe the phenomenon

Unlike the sunspots, however, of which we have records from very ancient times, no authentic record appears to be existent concerning observations of any projections beyond the Moon's dark limb, except that of the corona, which has been certainly recognised since the days of Kepler, about A D 1600

At the eclipse which occurred on July 8, 1842, we have the first accurate description of three rosy-red *protuberances*, projecting some distance beyond the edge of the dark Moon For some time later opinions still varied as to these features belonging to the Sun or the Moon, but it was definitely settled at a subsequent eclipse that they were part of the Sun's surroundings, because they were found not to partake of the motion of the Moon as it passed over the Sun during the eclipse

More careful observations served to prove that these rosy flames or protuberances were only the higher portions of what appeared to be practically a continuous ring of gaseous material, very close to the edge of the brilliant solar surface Soon after measurements made with telescopic apparatus furnished the infomation that this layer of seemingly coloured gas had a thickness of from 3,000 to 5,000 miles—not a great depth considering the Sun's total diameter of over 866,000 miles

In spite of these facts many otherwise well-informed people continued to believe that the projections might be caused by irregularities on the Moon's edge

All doubt, however, was finally dispelled by the satisfactory observations made photographically by Secchi and De La Rue at the eclipse of 1860, in Spain The protuberances were found to be quite independent of the Moon's motion, and henceforward they were regarded as truly solar appendages The important nature of this new advance acting as a stimulus, immediate arrangements were made for very extensive observations of all possible future eclipses

OPEN SLIT WITH PROMINENCE

Huggins found that by widening the spectroscope slit the complete structure of many prominences could be seen at one observation, and changes in their form more easily detected

Before the next eclipse, however, an additional method of research was being perfected in the application of spectrum analysis, and at the eclipse of 1868 it was found that the solar surroundings outside the Moon's limb were composed of gaseous substances which showed bright line spectra One of the chief constituents of this atmosphere first recognised was the well-known gas, hydrogen.

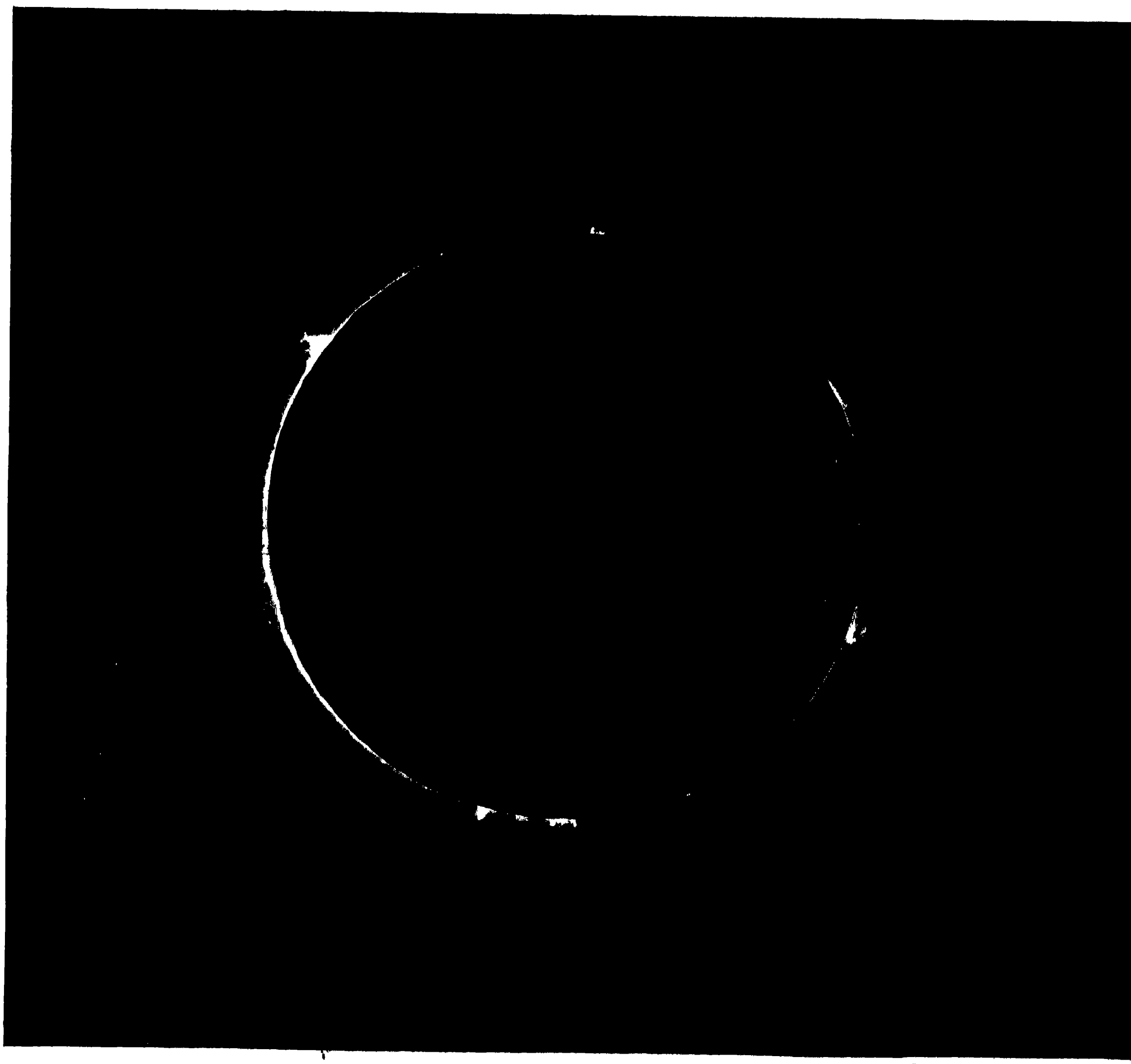
For the first time it was definitely proved that the light of the protuberances could not be due to reflected sunlight

The French observer at the 1868 eclipse was Janssen, who had made special spectroscopic preparations During the progress of the eclipse he was struck by the brilliancy of the spectrum lines

due to the solar prominences, so much so that he was encouraged to try again with the same instrument when the eclipse was over, and the brilliant sun-glare again became effective in masking all finer detail at the edge Next day he was able to test his idea, and he then made the successful and epoch-making discovery that the bright line spectrum due to the solar atmosphere could be observed with the spectroscope whenever the Sun was clear, without having to wait for the occurrence of an eclipse

Meanwhile, in London, Lockyer had quite independently devised the same procedure for seeing the prominences, and carried it out successfully This mutual discovery was commemorated by the French Government in 1872 by the special issue of a gold medal in honour of the two astronomers

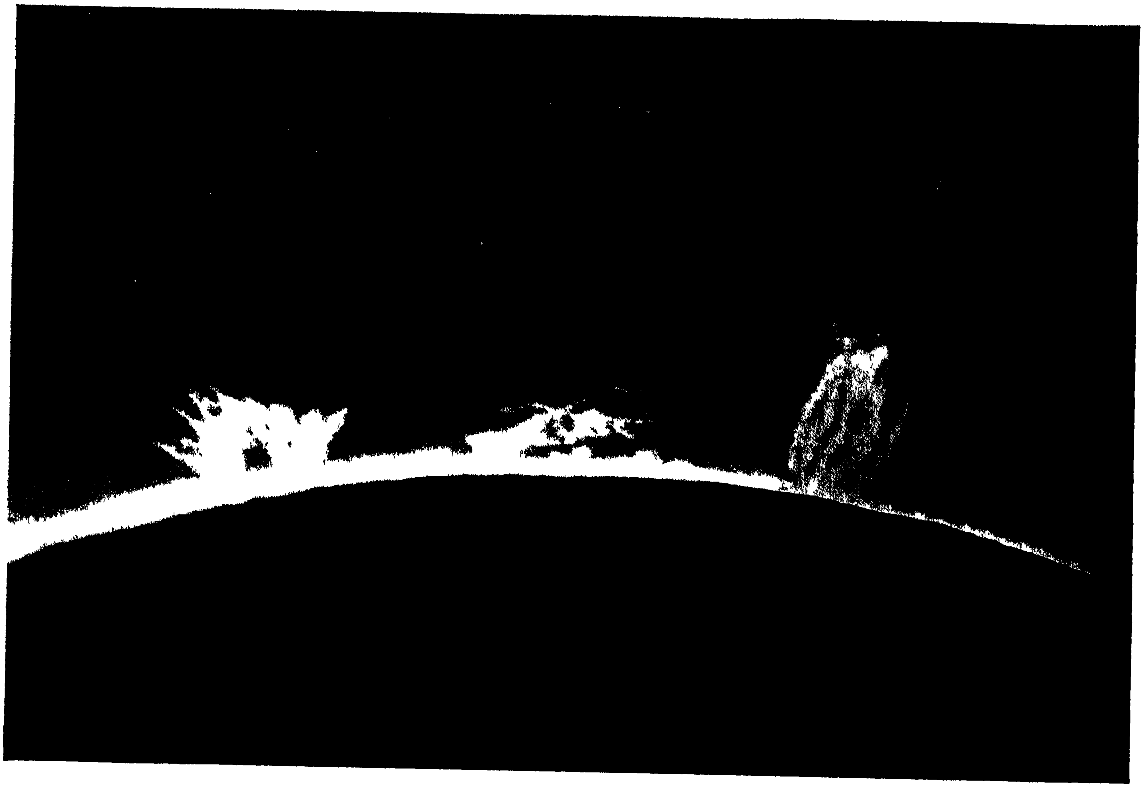
The principle involved in this new method of observation lies in the fact that if a mixed source of light consists of continuous radiation and also monochromatic radiation (*i e*, light of any one colour), any increase of dispersion by means of a spectroscope will gradually reduce the intensity of the



[Lick Observatory Expedition

SOLAR PROMINENCES AND CORONA

Photographed during Total Solar Eclipse of the Sun by the expedition from the Lick Observatory, California Part of the bright chromospheric ring is well shown along the right hand top quadrant Several groups of prominences are seen, mostly of the quiescent type, and they are distributed at widely different latitudes round the limb of the Sun The equatorial regions of medium latitude are those where the coronal extensions are greatest The prominences are distinct from, and of different nature to the corona



[*Barnard and Ritchey*

SOLAR PROMINENCES PHOTOGRAPHED AT ECLIPSE OF MAY 28, 1900

Records of the solar surroundings were obtained directly on a large scale by Barnard and Ritchey from the Yerkes Observatory, Chicago, located at Wadesboro', North Carolina. They used a coelostat-mirror, 12 inches in diameter, to reflect the sunlight through a photographic telescope, with lens 6 inches diameter and 61⅓ feet focal length. Three different types of prominence are shown, the left one like two sheaves of corn, the middle one almost tangential to the Sun's edge, the right one a massive pillar

continuous spectrum, while leaving almost unaltered radiations showing separate bright lines. These bright lines will be dispersed to greater distances from each other, but each simply remains an image of the spectroscope slit in whatever colour is being emitted: the lines of hydrogen, helium, &c., in the case of the solar atmosphere.

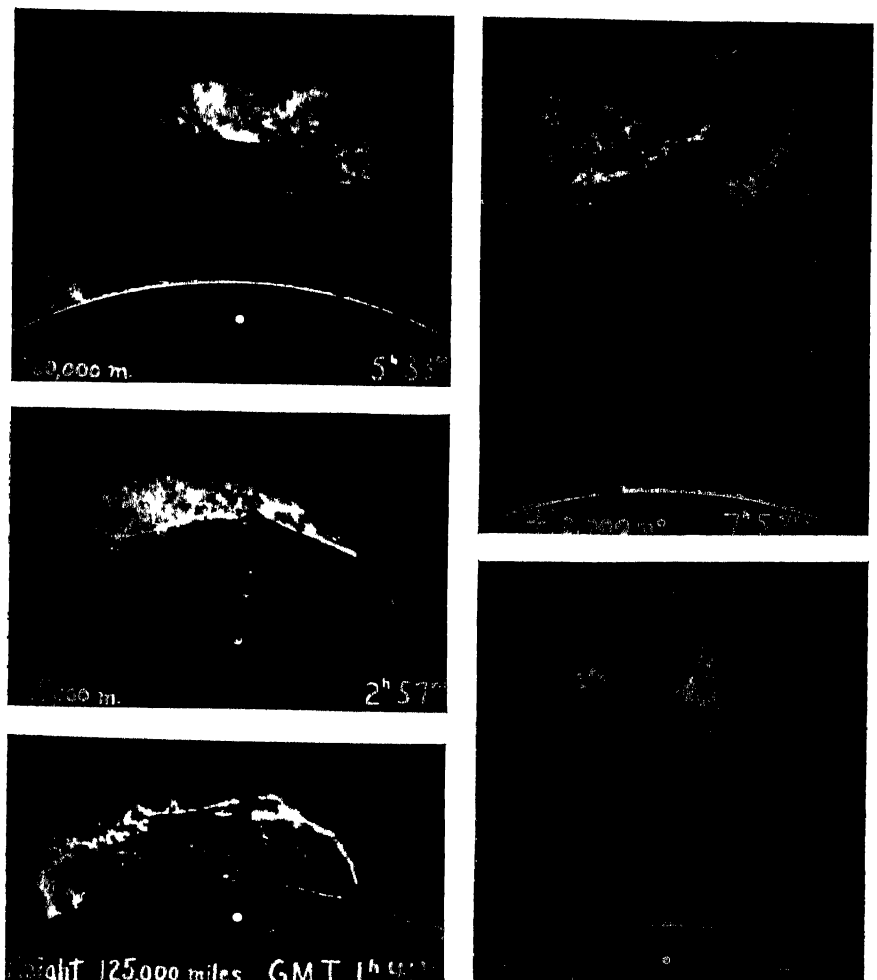
On account of the preponderating rosy colour due to the hydrogen, this luminous ring round the Sun was given the name *Chromosphere*, to distinguish it from the brilliant white disc with which we are generally most familiar, the *Photosphere*.

Another prominent constituent gave a characteristic yellow line close to the well-known double yellow line due to sodium, for which at that time no terrestrial equivalent was known, and it was christened *Helium* by Lockyer, one of its first observers. It was not until many years afterwards, in 1895, that this line was literally run to earth by the chemist Ramsay, who was able to prepare gas giving the same yellow line by the action of heat or acid on certain rare minerals. Later it was detected in many mineral springs at various places on the Earth, and can now be obtained in very large quantities.

An improvement of the method of observing was soon afterwards devised by Huggins, who found that if the instrument was provided with sufficient dispersing power it was possible to see the whole image of each prominence by widening the slit. The background of illuminated sky, however, is also increased so that a limit is soon found beyond which the slit must not be opened. The new method proved a very great convenience, conducing to rapidity of observation, as details of the prominence structure could be detected which might be lost if successive settings had to be made with a narrow

slit Moreover, when a complete prominence could thus be kept under observation, any changes, which are often extremely rapid, could be more accurately detected

In 1870 Young, in America, observed the total solar eclipse by the new spectroscopic method, and made the first record of the fact that, at the instant of complete obscuration of the photosphere, many hundreds of bright lines were visible, amounting to what he considered a complete reversal of the ordinary dark Fraunhofer lines Believing that this was due to a definite layer surrounding the photosphere, which by its absorption produced the dark line Fraunhoferic spectrum, he called the stratum the *Reversing Layer* Many attempts were made to photograph this at subsequent eclipses, but owing to the extreme difficulty of adjustment necessary to catch the exact instant when the lowest stratum was uncovered, this photographic record was not obtained until it was made by Shackleton in Nova Zembla in 1896, using a prismatic camera or slitless spectroscope Subsequent records of this *reversing layer* or *flash spectrum*, as it is frequently termed, have been obtained by Lockyer, Evershed, Mitchell, and Dyson



By permission of] [*The Yerkes Observatory*

THE GREAT SOLAR PROMINENCE, MAY 29, 1919

Photographed with the spectroheliograph at the Yerkes Observatory, Chicago The first picture, bottom left, taken at 1h 41m, shows the prominence with general form very similar to that shown on the Eclipse picture The other sections indicate the rapid changes in the form of the prominence during the next six hours, in the course of which it attained a height of 410,000 miles above the Sun's limb On two of the pictures portions appear to be floating in the chromosphere, quite disconnected from the Sun's limb

Systematic observations of prominences were instituted by Tacchini at Rome in 1872 Records were made of their number, height and position round the limb of the Sun To define their positions, north was taken as zero, 0°, and angles reckoned by degrees through 90° at east, 180° at south, 270° at west, back to 360° or 0° again at north Accurate sketches were also made whenever possible

The work was continued by Ricco and Mascari at Catania, in Sicily, and testimony to the value of these Italian observations is found in the long series of prominence records published by the Italian Spectroscopic Society

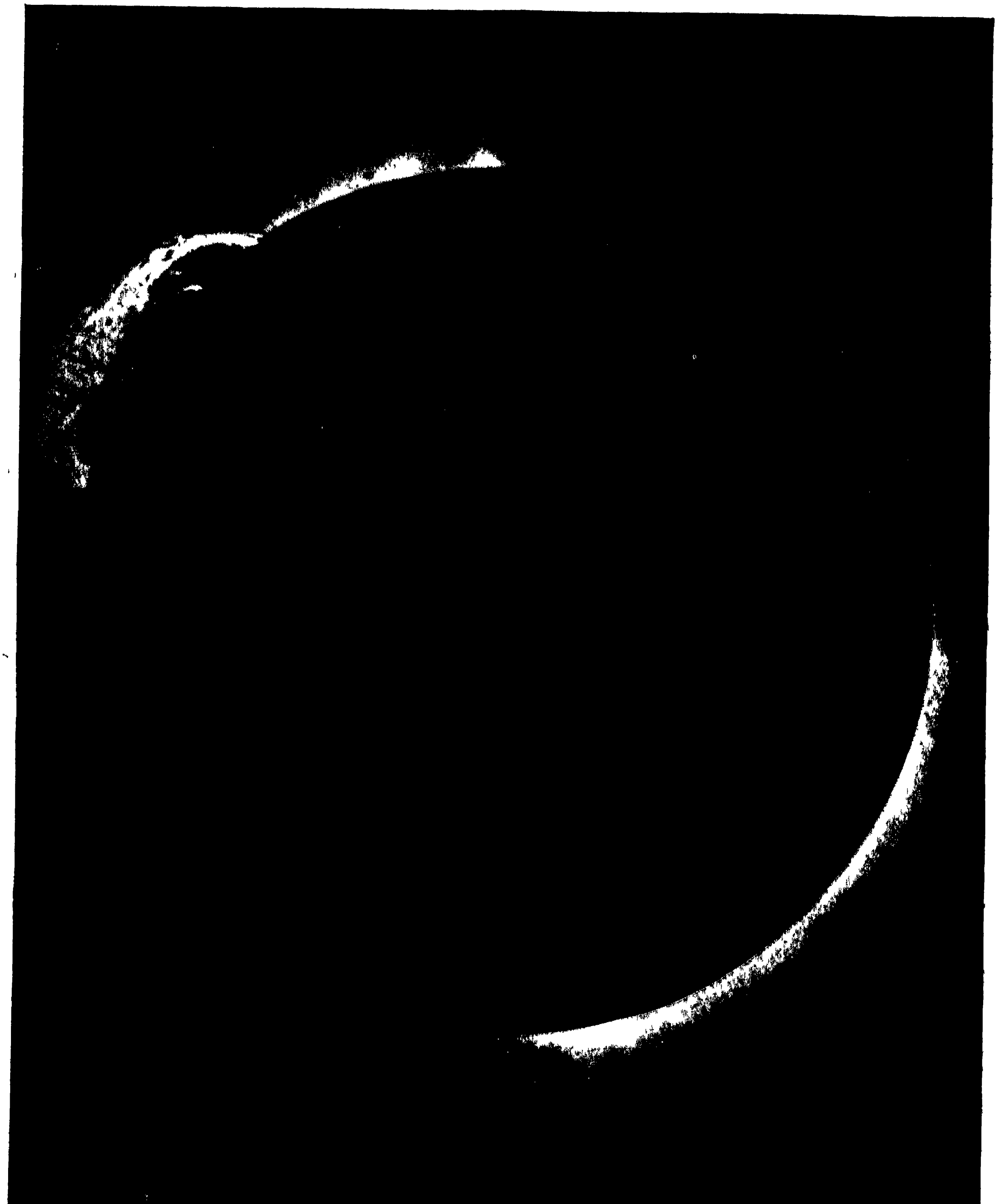


Photo by] [*A C D Crommelin*

ECLIPSE PROMINENCE AND CORONA, MAY 29, 1919

Photographed during the Total Solar Eclipse by observers from Greenwich Observatory The two bright extensions outside the limb of the dark Moon are the lowest portions of the inner corona The beautiful prominence exhibited very rapid changes throughout the day of eclipse The material appears to be thrown out from the funnel-shaped portion at the lower end of the prominence, and gradually rises to form the complicated cloud like mass which runs almost parallel to the Moon's edge for about 30° Then parts of the material appear to fall and follow a curved track until they meet the Moon's limb close to the coronal streamers Note also the beautiful curved wisps falling inside the main descending arch

Long series of observations were also made by Fenyi at Kalocsa, published in separate volumes from that observatory, by Evershed at Kenley, Surrey, and Kodaikanal, India, recently published in an important memoir of the Kodaikanal Observatory, and by Fathers Perry, Sidgreaves, and Cortie, at Stonyhurst Observatory, England

Photo by] [Yerkes Observatory

QUIESCENT AND ERUPTIVE PROMINENCES

Two prominences are shown at the limb, one small, on the left, the other much larger and roughly conical Comparison of this picture with the next will show that the small prominence is almost exactly the same shape and size in the two photographs It is a quiescent prominence This type often lasts for long periods

Quite early in the history of systematic prominence observation it became evident that these objects could be divided into two main classes, dependent on their general form and degree of activity These were called *Quiescent* and *Eruptive*

Quiescent prominences are the diffused cloud-like masses which are frequently observed near the same places for long periods without much evidence of violent change They may assume an infinite variety of forms, much as our terrestrial clouds do, from delicate cirrus tracery to great massive cumulus types Some times they are connected to the chromosphere by a slender neck or a series of columns, at others they appear to lie bodily on the surface of the chromosphere, though this may be due to the connecting columns being out of sight on the spherical surface of the Sun Prominences of this type are frequently from 60,000 to 100,000 miles high, and at times masses are seen to form apparently by condensation about their position, with no evidence of having been projected from the chromosphere

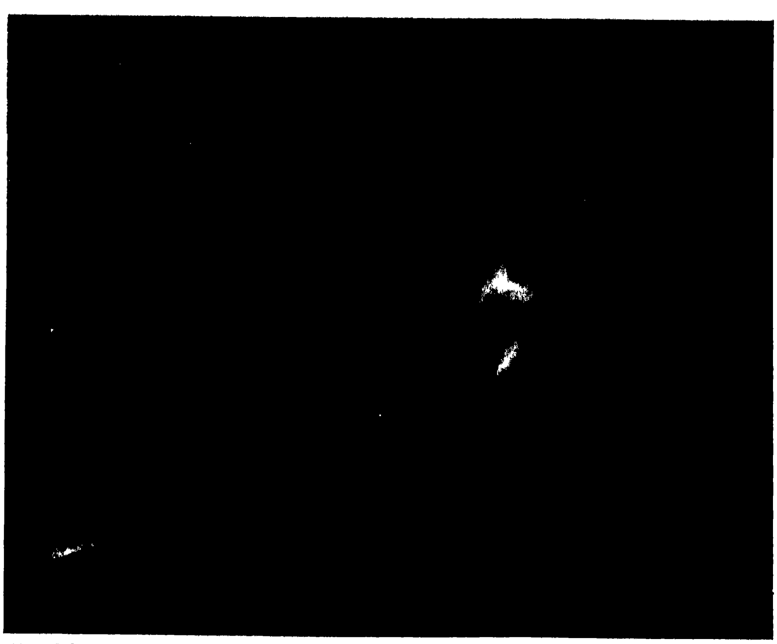
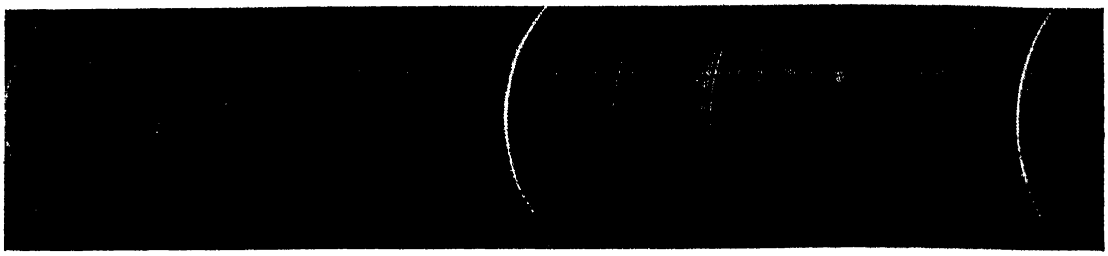


Photo by] [Yerkes Observatory

QUIESCENT AND ERUPTIVE PROMINENCES

While the small prominence is almost unchanged from the last photograph, the larger prominence on the right is seen to have become entirely altered Its height has increased about three times, and the whole of its material appears to have been blown about in different directions, due to some eruptive force

Eruptive prominences are quite distinctively opposite in character to the quiescent



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SPECTRUM OF THE SOLAR CHROMOSPHERE, MAY 28, 1900

Photographed by Lord with a large telescopic camera having a prism placed outside the object glass The bright arcs are images of the chromosphere in the spectrum lines of Hydrogen, Helium, Calcium, Iron, etc The different lengths of the arcs are due to the varying heights of the elements in the solar atmosphere

type They are seen to be in rapid motion, and most frequently they take the form of jets These are often found in the neighbourhood of active sunspot groups, which may be near the edge at the time, and there appears to be considerable evidence that many of them are due to ejection from the sunspot areas In the records of their motions velocities up to 200 to 300 miles per second have been noted At times these objects are so brilliant that with the spectroscope the bright lines due to their spectrum may be observed even on the disc of the Sun

Taking the diameter of the Sun's disc to be about thirty-two *minutes* of arc (=866,000 miles) the average depth of the chromosphere may be given as about ten *seconds* of arc, corresponding to about 5,000 miles

The upper edge of this layer presents a disturbed appearance which has been likened to the edge of a saw Part of this may of course be due to disturbances of the telescopic image produced by the unsteadiness of our own terrestrial atmosphere It is the larger peaks of this disturbed stratum to which we give the distinction of protuberances or prominences To make the observations more definite, it is usual not to count an object as a separate prominence, apart from the chromospheric serration, unless it is higher than about twenty seconds of arc, say 9,000 to 10,000 miles, and tables of prominence records must be inspected with this limitation in mind

By permission of] [*The Yerkes Observatory*

ERUPTIVE PROMINENCE AND SUNSPOT GROUP

Showing the association of the plume or fountain shaped eruptive jets in close proximity to a disturbed sunspot group near the edge of the Sun The other prominences seen along the Sun's limb, farther from the spot group, are more quiescent

On October 7, 1880, Professor Young, at Princeton, in America, observed a prominence extending some thirteen minutes of arc above the south-eastern limb of the Sun This would be at least 350,000 miles high

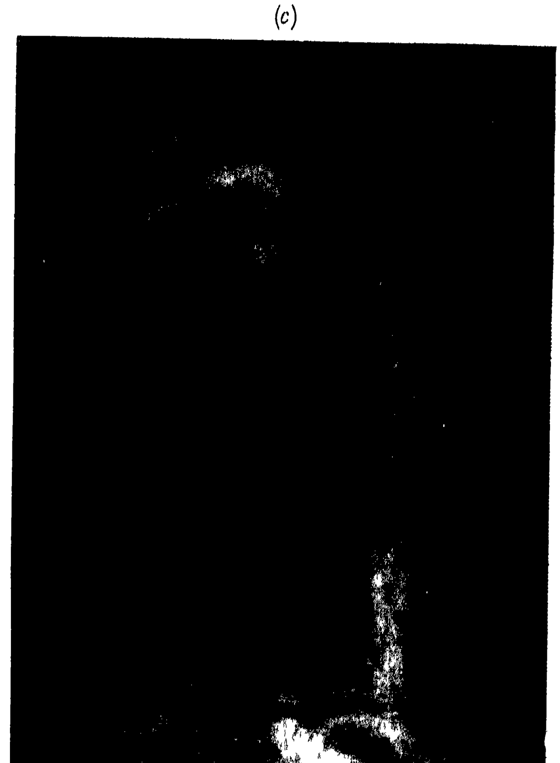
A prominence of exceptionally active nature was photographed at two stations in India in 1916, May 26, by Evershed, at Srinagar in Kashmir, and by Royds at Kodaikanal Fragmentary details of prominence material are shown at heights of more than eighteen minutes of arc above the solar limb Measurements of the changes shown in several of the recognisable details indicate velocities up to 457 kilometres per second

Another extremely high prominence was photographed by O J Lee at the Yerkes Observatory on October 8, 1920, which reached the height of nineteen minutes of arc, corresponding to 831,000 kilometres or 516,000 miles It did not appear to be

(a)

(b)

(c)



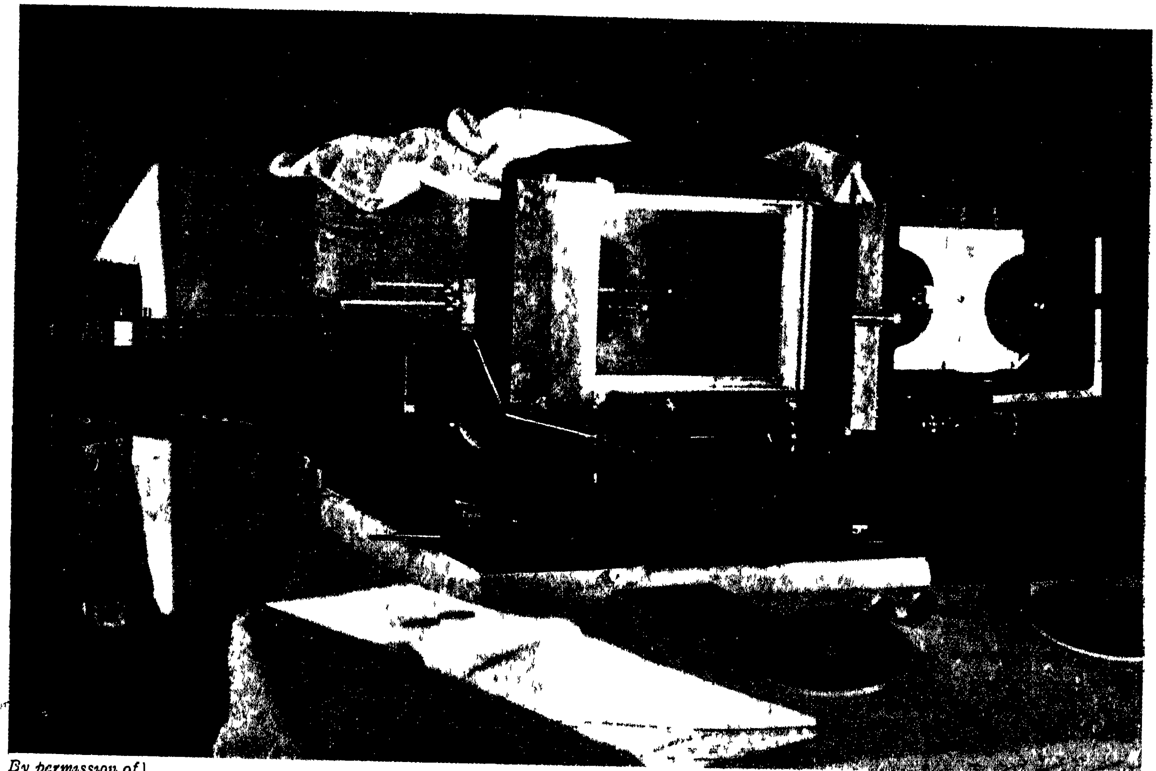
QUIESCENT AND ERUPTIVE PROMINENCES

(a) Arched form of Quiescent Prominence This type often presents the same appearance for many hours together (b) Eruptive Prominence photographed by Hale, at the Kenwood Observatory, Chicago, on March 25, 1895, at 10h 40m The top of the prominence is travelling away from the Sun's limb, but is also beginning to fall over The top of the prominence arch is about 162,000 miles above the Sun (c) The same prominence photographed only 18 minutes later, showing the material driven to a much greater distance from the Sun, to a height of 281,000 miles

associated with any sunspots on the disc During its process of formation parts of it moved upwards from the Sun with velocities of at least seventy-seven kilometres or forty-eight miles per second

Another great eruption occurred on the day of the total solar eclipse of May 29, 1919, when the prominence illustrated was photographed at many widely separated stations This attained a height of seventeen minutes of arc = 760,000 kilometres = 470,000 miles, and also exhibited wonderful changes in the details of its structure

Most of our readers will probably be familiar with the change of pitch of an engine whistle, approaching or receding from a station Similar changes in pitch are observed with waves of light, when the source which is emitting them is in motion towards or away from the observer In this case the wave-length or colour of the radiation is changed, and from the amount of this change it is possible to calculate the velocity with which the source of light is moving



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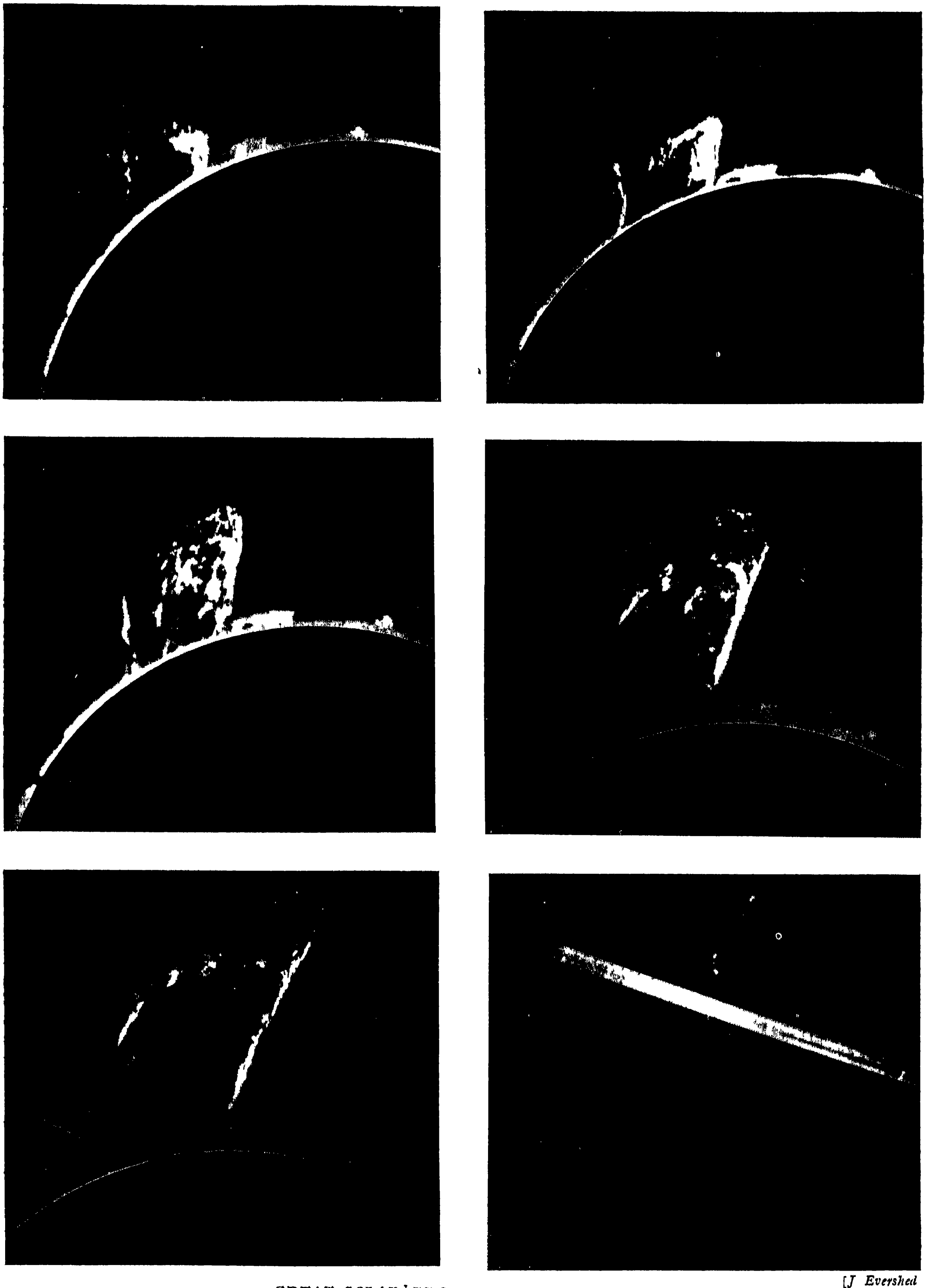
5 FT SPECTROHELIOGRAPH AT MOUNT WILSON, CALIFORNIA

The main portion is the spectrograph with collimator and camera 5-feet long On the right is the primary slit, with round brass disc to fit the image of the Sun In the middle is the camera box, inside which may be seen the secondary slit, for isolating the special spectrum line with which the photograph is to be taken On the left is the mechanism for moving the whole instrument smoothly and uniformly past the stationary image of the Sun on the primary slit

Such an application of Doppler's principle, as it is called, has for many years been applied to determining the velocities found in the solar prominences Careful scrutiny of the spectrum lines shows that they are frequently so altered as to appear distorted, sometimes being shifted towards the red, indicating that the prominence material is travelling away from the Earth, at other times the deflection is towards the violet end of the spectrum, showing that the material is coming towards the Earth

By combining these velocities in the line of sight with those determined in the plane normal to that direction, which latter are given by the direct measurements of the changes in the prominences, some idea of the real motions of the gases in the solar atmosphere have been obtained



[J Evershed

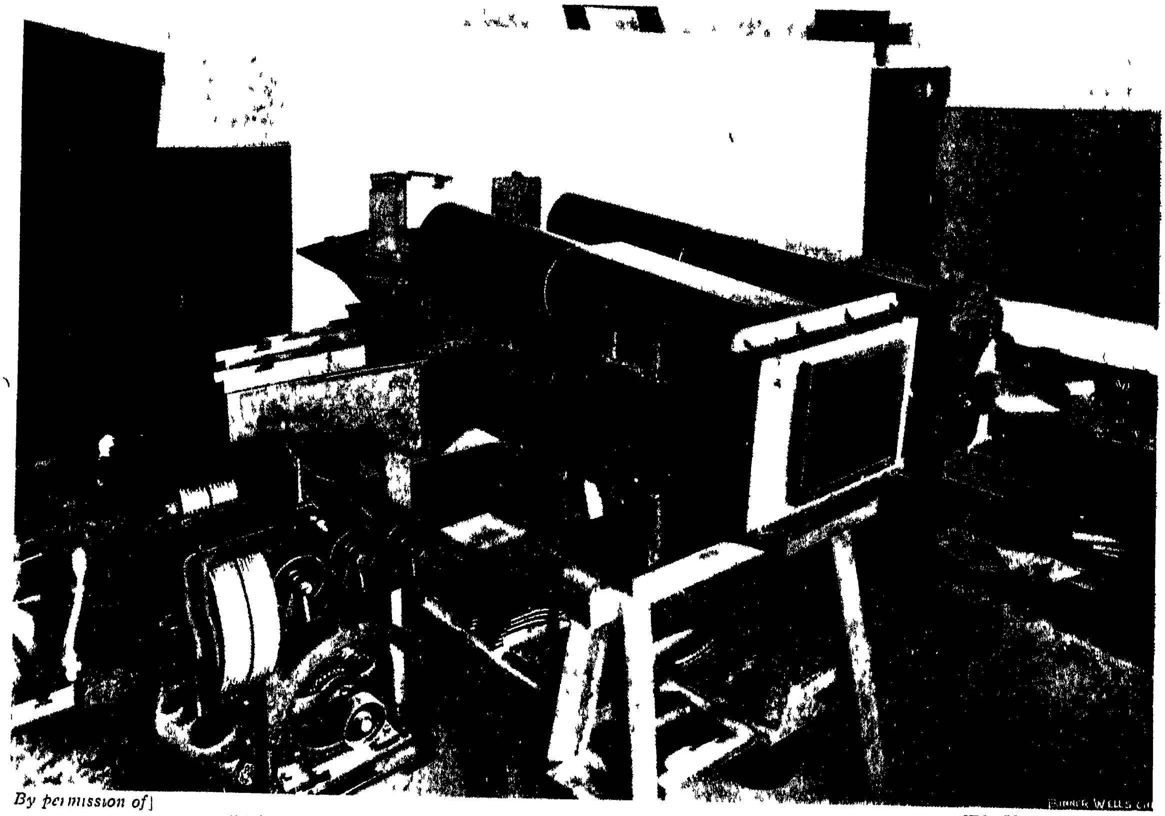
GREAT SOLAR PROMINENCE, MAY 26, 1916

Six photographs taken with the spectroheliograph belonging to the Kodaikanal Observatory, India During the earlier stages the changes in detail are very striking, but one characteristic feature persists throughout the series—the appearance of the gaseous matter being blown away over to the left side by some force from the right Notice the remarkable straightness of the main streak on No 4, before the material begins to stream away to form the arches Many of the fragmentary portions reached a height above the Sun's edge of 480,000 miles During the eruption various portions of the prominence matter moved with velocities of 280 miles per second

An interesting result of such calculations is to show that a great number of the eruptions on the Sun appear to be of spiral structure, sure indication of some vortical or whirlwind type of motion. We shall see later that this is beautifully shown by other phenomena on the Sun's disc, and evidently is one of the distinctive features of the solar activity.

Observations during eclipses show that although certain substances, such as hydrogen, calcium, and helium, are present in all parts of the solar atmosphere, other elements, chiefly those of moderate atomic weight, evidently occur in localised strata, partly but not entirely in proportion to their atomic weight. These lower layers show the spectra of sodium, iron, titanium, magnesium, strontium, &c.

Although in general the spectrum of the chromosphere may be considered as being a reversed Fraunhofer spectrum, it shows many differences in the relative strengths of various classes of lines.



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5 F1 SPECTROHELIOGRAPH AT MOUNT WILSON, CALIFORNIA

Side view of the instrument showing the two spectrograph tubes, fixed parallel to each other. The one to the right is the collimator, carrying the primary slit, and brass disc in position to cover the Sun's image. The left-hand tube is the camera, with the dark slide holder in the large box at the front end. The whole instrument is on ball bearings, and most of its weight is taken off the supports by being floated on mercury. On the extreme left is the driving mechanism and electric motor for traversing the instrument across the Sun's image.

The most notable of these divergencies is the preponderance of what are known as *enhanced lines* of the elements concerned.

When an element, for instance iron, is vapourised under different sources of heat, say an ordinary furnace, the electric arc, or the spark from an induction coil, it is found that while many lines occur under all these different conditions, there are in addition certain radiations which appear under particular circumstances. The special lines which are shown in the *spark* spectrum of any element are known as the *enhanced lines* of that element.

It is by following up such facts in the co-ordination of work in the physical laboratory and astro-

physical work in the observatory, that we are enabled to form some idea of the relative conditions governing the various parts of the solar surroundings.

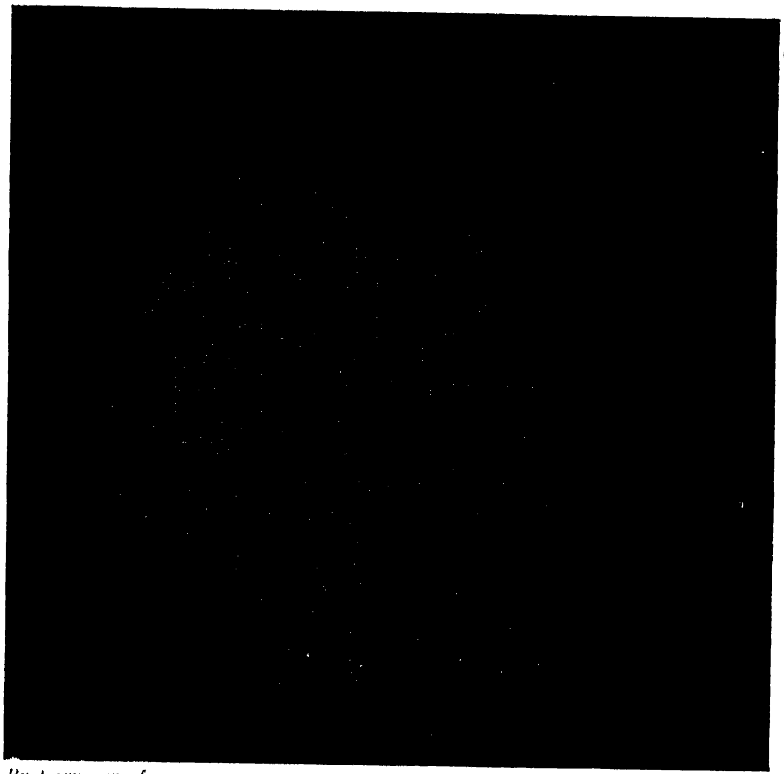
The results obtained from a study of the distribution of solar prominences have given most interesting and important information in connection with the question of the solar activity. Mention has been made in a former section of the regularity of distribution of sunspot areas. It is somewhat more difficult to determine the actual laws of distribution of prominences over the Sun's surface, as to some extent we are limited in only being able to observe these phenomena at the edge of the Sun. All but the smallest features are then seen in projection along the line of sight, and some may even be only the tops of very high prominences which originate either on the side of the Sun away from the observer, or on the side towards him, but hidden by the great glare of the photosphere.

For a great number of years, however, valuable observations have been accumulated by several observers, notably Tacchini at Rome, and Ricco and Mascari at Catania in Sicily.

All these observations are arranged to show the positions of the prominences referred to the true axis about which the Sun is known to rotate, and which has been accurately found from the observations of sunspots.

It will be remembered that sunspots are generally confined to what may be termed the intermediate zones of the Sun's surface (corresponding roughly to the temperate zones of the Earth), between 5° and 40° latitude in either hemisphere. Sometimes, indeed, they occur in the equatorial zone, but it is very rarely that a sunspot is found farther north or south than 45°.

Prominences, however, suffer no such limitation. They may occur at any latitude from the equator right up to the solar poles.



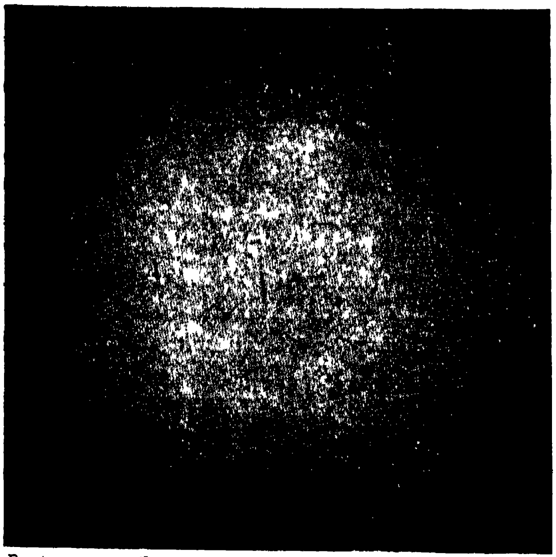
By permission of] [The Yerkes Observatory

SUN WITH SPOTS ONLY

Photograph taken with ordinary light from the Sun. This shows only the bright white disc with several black spots. At times bright faculæ are photographed near the edge, but very seldom near the centre of the Sun, owing to the brilliant glare from the rest of the surface of the solar photosphere.

There is some distinction between the zones of occurrence of the two main groups into which prominences are classified. The eruptive or explosive prominences are chiefly confined to the sunspot zones from the equator to 40° north or south latitude. It is the so-called quiescent or cloud-like prominences which have the wide range of distribution in solar latitude from pole to pole.

Taking those prominences which do occur at all places on the Sun, and examining their positions from year to year, it is found that these positions, taken individually, show a regular change of position according to the epoch of the solar cycle at which they are observed. It must be understood that there is continual birth and death of prominences, and it is their position which shows this regular change.



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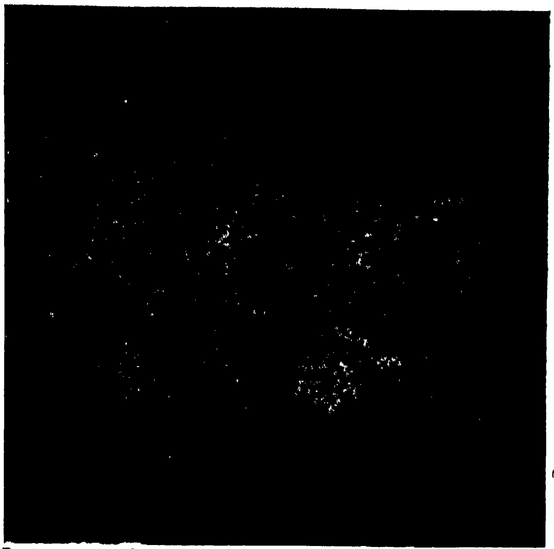
DIRECT PHOTOGRAPH OF SUN, AUGUST 25, 1906

Taken at 6h 9m with all light, showing the black spots only Near the edge may be seen small patches of bright cloud material, the faculæ



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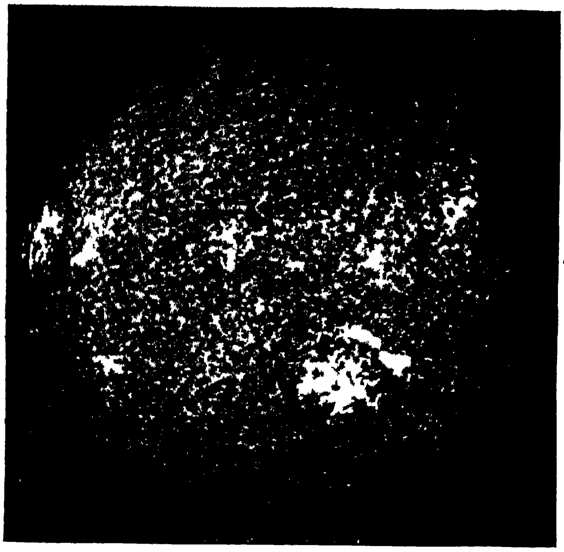
SUN PHOTOGRAPHED WITH 5 FT SPECTRO-HELIOGRAPH, AUGUST 25, 1906

Taken at 6h 22m with the ultra-violet line of calcium vapour (H_1) In addition to the spots and the *bright* patches near the edge, bright clouds are now shown in many places on the body of the Sun, especially round the spots

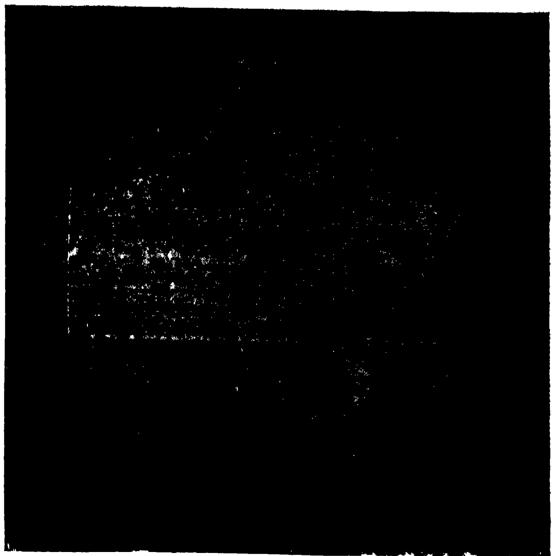
Two zones of activity are usually exhibited One following the sunspot variation more or less closely, and running from about 35° latitude just after minimum activity to low latitudes about 5° at some time before the next minimum The other starts at about latitude 40°–50°, just after maximum activity, and gradually changes to high latitudes, finishing at the poles in either hemisphere about the time of the succeeding maximum



By *permission of*] [*The Yerkes Observatory*

SUN PHOTOGRAPHED WITH 5 FT SPECTRO-HELIOGRAPH, AUGUST 25, 1906

Here we have the slit of the spectrograph set on another part of the calcium line (H_2), which records the calcium vapour at a different level in the solar atmosphere, and consequently the *bright* patches have somewhat different shapes from those shown with (H_1)



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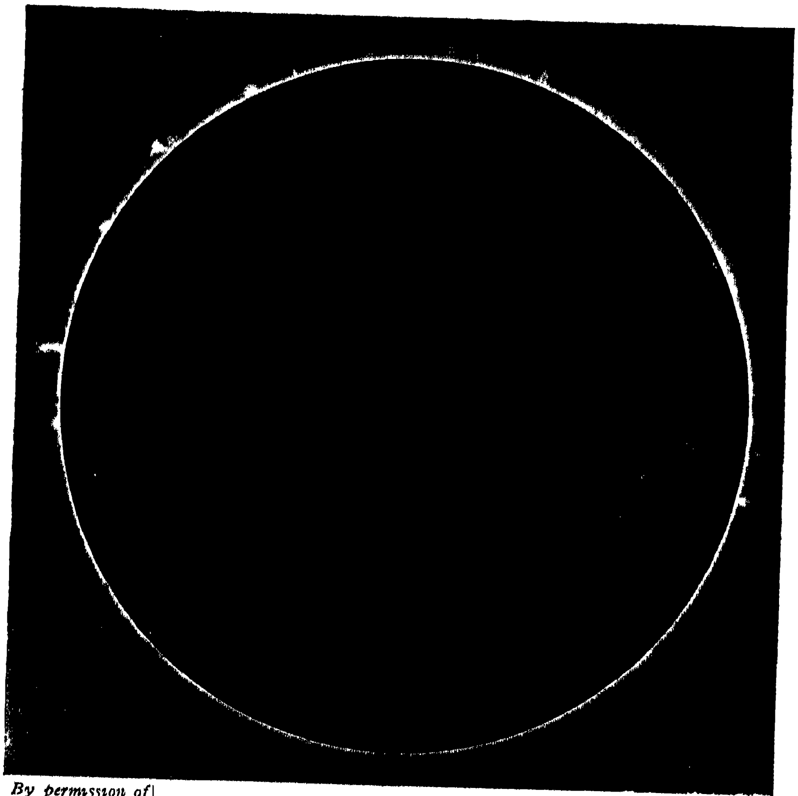
SUN PHOTOGRAPHED WITH 5-FT SPECTRO-HELIOGRAPH, AUGUST 25, 1906

Quite a different appearance is presented when photographed with hydrogen ($H\delta$) The clouds round the spot centres are now *dark*.

Despite the fact that the first photograph of a prominence in full daylight without an eclipse was obtained by Young in 1870, and subsequent attempts with modifications of similar apparatus were made by Braun in 1872, and later by Lohse, no material success in the organisation of continuous photographic observations was attained for some twenty years

A new era was inaugurated when G E Hale started experiments at Harvard College in 1889–90 and continued them in a private observatory at Chicago—the Kenwood Observatory Here he devised an instrument consisting of a spectroscope arranged to take a continuous series of photographs of strips of the solar image from one limb to the other, the motion being so truly regulated that the images had little distortion By passing the Sun's light through the moving spectroscope it was possible to control the wave-length or colour of the light which was allowed to emerge, so that photographs could be taken in any kind of light, from red to violet, just as if a coloured screen had been interposed in the camera The advantage over a coloured screen was that the requisite selection of colour transmitted could be made much more delicate, almost amounting to the isolation of a single wave-length of light



By permission of] [The Yerkes Observatory

SOLAR PROMINENCES WITH SPECTROHELIOGRAPH

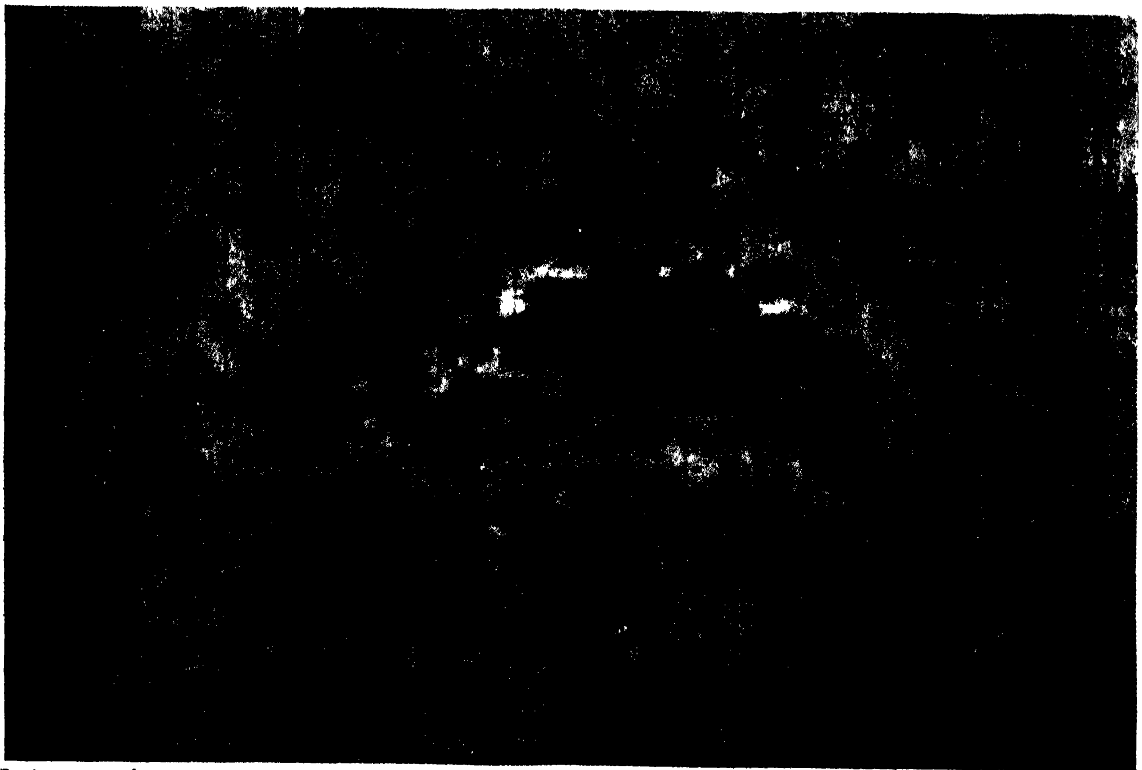
Showing the chromosphere and prominences taken with the spectroheliograph without an eclipse Comparison should be made with a previous picture (page 157), which was photographed during a total solar eclipse The prominences are almost equally well shown in the two pictures, but on the spectroheliograph record there is no trace of the solar corona, which has, up to the present time, only been detected during total eclipses of the Sun

The instrument was first devised with the object of facilitating photography of prominences, and at its first trial at Harvard in 1890 was not successful owing to the faintness of the hydrogen image then chosen Continued study showed that all prominences were very rich in ultra-violet radiation, particularly that of *calcium* as represented by the intense lines denoted H and K by Fraunhofer The improved instrument, with which very satisfactory results were obtained at Kenwood, is shown in an accompanying illustration in a former section (p 66) In this early instrument the arrangement embodied movable primary and secondary slits, while the solar image and photographic plate were fixed The new era of satisfactory delineation of both chromosphere and prominences round the entire limb of the Sun may be thus dated from results obtained with this instrument in 1892

Almost immediately after this success, the principle of the spectroheliograph was extended to the portrayal of detail on the disc of the Sun Hale, and also about the same time Déslandres, of the Paris Observatory, had found that ordinary slit spectrograms of the Sun's surface gave from time to time evidence of brilliant reversals of certain of the dark Fraunhofer lines, particularly the same H and K lines of calcium, and the ultra-violet lines of hydrogen

Ordinary photographs of the Sun, taken with the whole of the light, show little more than the spots and the bright patches of faculæ near the edge As these were specially rich in the bright calcium radiation, it was soon found that pictures taken with these special lines through the spectroheliograph showed all the details, not only near the edge, but wherever on the disc of the Sun they happened to exist This was immediately seen to be a most important advance

Great bright masses of cloud-like material were often found on the surface, which were quite invisible on the photographs taken by the old method with the whole of the integrated light from the Sun Some intimation of the presence of such areas had been obtained by the visual observations of Young and other solar observers, when they found bright reversals of the H and K lines in the neighbourhood of sunspots on the disc



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DARK AND BRIGHT HYDROGEN FLOCCULI, OCTOBER 9, 1903

Photographed with hydrogen light with spectroheliograph showing the strong dark and bright hydrogen flocculi surrounding the great Sunspot The vortex stream lines are well shown over a large area The relations between the dark and bright patches enable the observer to obtain some idea of the relative level of the mixed materials in the cloud regions of the Sun's atmosphere

Ordinarily the appearance of a solar photograph presents the bright disc, the black spots, and faculæ or brighter masses near the edges This is shown in an accompanying photograph The appearance shown by the new spectroheliograms, as they are now called, when taken by the pure light of calcium or hydrogen, as the case may be, is illustrated by other reproductions

Important differences are shown according to the individual spectrum line chosen to make the picture, as will readily be appreciated on comparing the results obtained with calcium and hydrogen on the same day

While the general forms and positions of these bright clouds photographed with the new instrument appeared to be closely related to the faculæ, it was not certain that they were identical, and to distinguish them Hale proposed to call them *flocculi*, from the chief characteristic of their structure in billowy masses

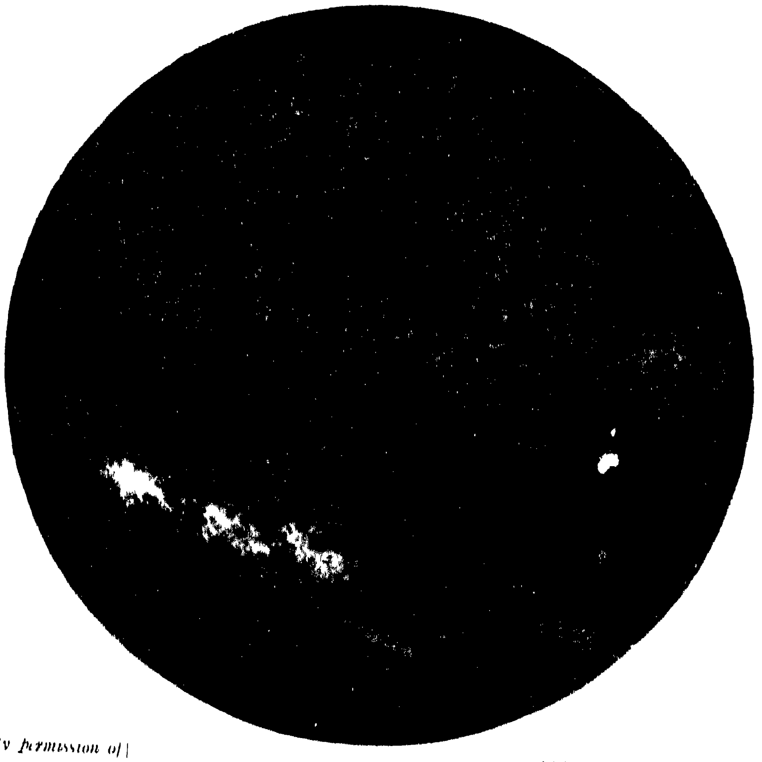
About the same time Déslandres was working on similar lines at Paris, and excellent pictures were being obtained with an instrument of similar function, but somewhat different in design.

Progress with the new method was rapid, and with perfection of detail, and it became possible to institute routine methods for the daily registration of the solar activity by its means. This was done by measuring the areas of the bright calcium clouds shown on the photographs from day to day. They were found to vary in amount in close relationship to the areas of sunspots, in the period of about eleven and a quarter years, called the solar cycle.

Measurements of the positions and rates of motion of the calcium flocculi gave new data for the period of the Sun's rotation on its axis, and, with certain differences from the values found by means of the movements of sunspots, the results indicated similar *variation* of rotation velocity at different latitudes on the Sun's surface. The flocculi nearest the equator moved faster than others at higher latitudes in either hemisphere.

It was soon found that the work demanded for its satisfactory prosecution a larger instrument than that at Kenwood, and in the institution of the new Yerkes Observatory of the University of Chicago, about 1895, Hale made provision for a spectroheliograph of much greater power.

The Yerkes refracting telescope, of forty inches aperture, gave a solar image of seven inches diameter, while that at Kenwood was only two inches, and this involved difficulties in the design of the optical system to transmit such large angular separations. These were overcome, and the resulting Rumford spectroheliograph became the medium of important advances in the research on the solar atmosphere. In this instrument the spectroscopic equipment with its two slits is fixed, while the solar image and photographic plate are moved across the slits by suitably geared electric motors. The increased scale of the photographs sufficed to show much more detail, as may be seen on two of the spectroheliograms taken with it which are here reproduced.



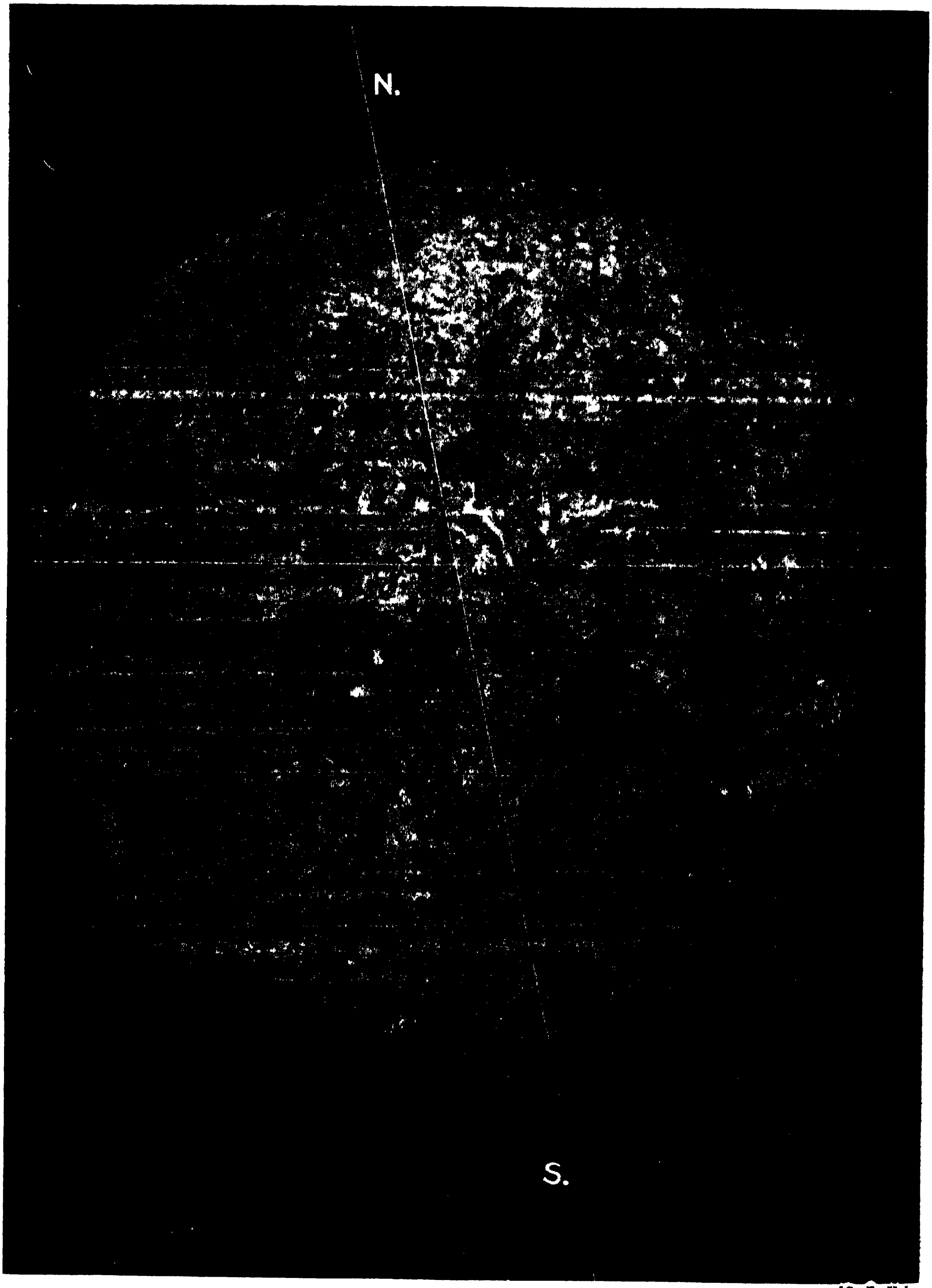
By permission of [*The Yerkes Observatory*

CALCIUM FLOCCULI ON THE SUN

A typical spectroheliogram of the Sun, showing the brilliant clouds or flocculi. This would be taken with the bright centre (H_2) of the ultra violet calcium line. Note the occurrence of the flocculi in two belts. Also each of the three brighter masses is longer than it is broad, and their inclinations are all in the same direction. The inclined portions all point to the western side of the equatorial zone.

While the initiation of this new sphere of solar investigation is due to Hale and Déslandres, their example was soon followed at many of the leading observatories of the world.

Evershed was the first in England to construct a spectroheliograph, and after various experimental trials one was installed by Sir Norman Lockyer at the Solar Physics Observatory, South Kensington, and removed to Cambridge in 1913. Another of similar design was taken in 1902 to the new Solar Physics Observatory at Kodaikanal, South India, by the writer, who spent some time there instructing



[G. E Hale

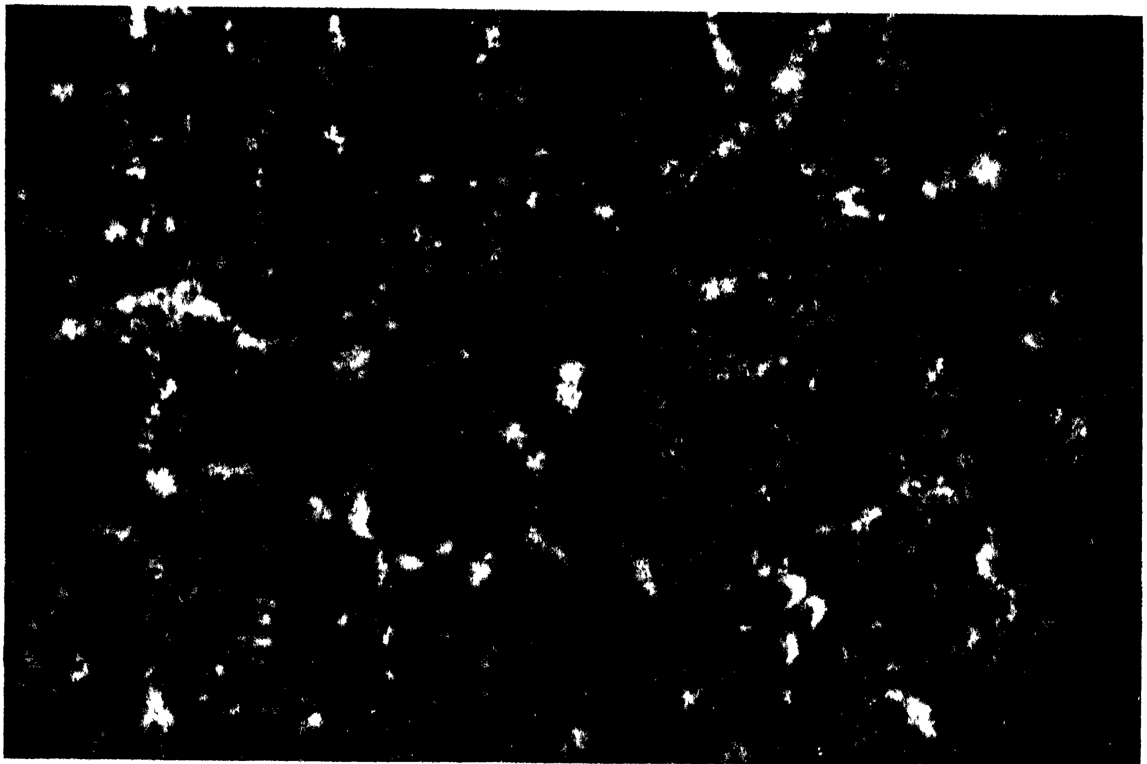
SUNSPOT VORTICES

Showing the enormous size of two solar disturbances, with a spot at centre of each This spectroheliogram was taken in the red light of hydrogen (H_{α}), and is thought to represent the upper layers of the solar atmosphere These enormous whirlpools contain charged particles rotating in the vortex, thus producing a magnetic field in the region of the spot This modifies the radiation coming from the centre of the spot, causing the lines of the spectrum to become multiple in their structure The direction of the Sun's axis is indicated by the line N S, and it will be seen that the direction of rotation of the vortex stream lines is opposite about the two spots, one of which is in the northern, the other in the southern hemisphere

the staff in astrophysical work Later, in 1908, Evershed was appointed Director at Kodaikanal, and the subsequent development of solar and general astrophysical observation has provided a great amount of valuable data for future investigation

There are also spectroheliographs installed at the continental observatories of Catania (Sicily); Tortosa and Madrid (Spain), Potsdam (Germany) The Government of Japan is also considering the provision of similar equipment on a large scale for several branches of solar investigation It is also hoped that solar observations will in the near future be organised in Australia and Russia

After considerable experience had been gained by the work with the broad calcium line, which offered special facilities, attempts were made to utilise the radiation from spectral lines of some of the other elements which were known to exist in the solar atmosphere First, of course, with the



By permission of] [*The Yerkes Observatory*

MINUTE DETAIL OF CALCIUM FLOCCULI

With the large instruments now employed, the minute structure of the solar surface can be closely studied This is apart from any of the great flocculi masses, and the whole of the Sun's surface is dotted with these bright and dark specks of calcium vapour The appearance is called the solar réseau

lines of hydrogen, which in the earlier work had only been unsuccessful on account of the small power of the older instruments

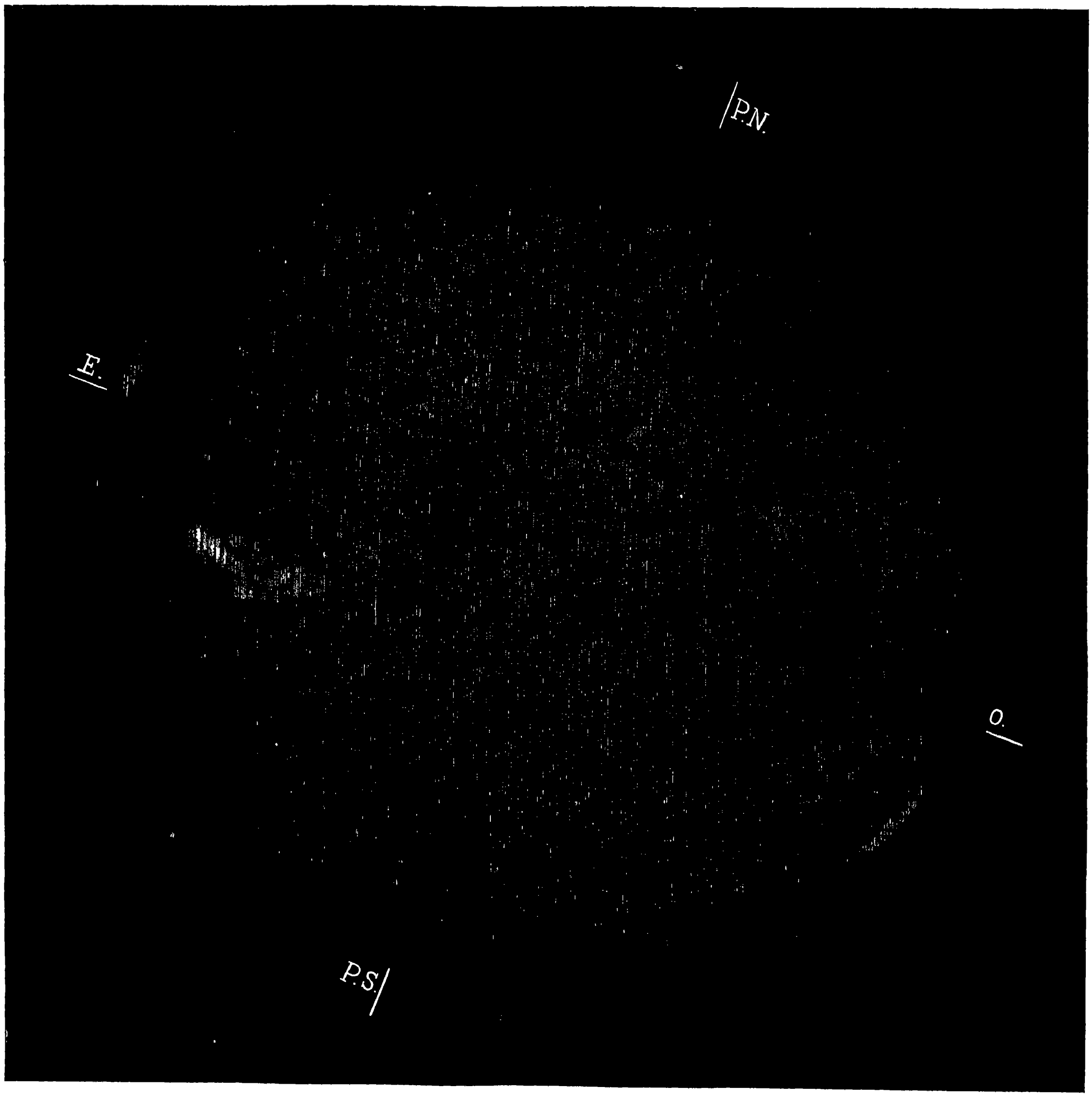
By substituting a diffraction grating for the dispersing medium in the spectroscope, very successful results were obtained with hydrogen lines, particularly with the red line H_α

The photographs thus obtained showed solar clouds with very similar *forms* to those taken with calcium light, but with the important distinction that, whereas the calcium clouds were *bright*, most of the hydrogen clouds were *dark* At times, in regions where there was obviously an eruption proceeding, and in the vicinity of disturbed sunspots, there were occasionally found bright hydrogen flocculi

This curious result has provided material for much discussion, and the interpretation is still surrounded with difficulty The explanation most favoured by Hale, their chief observer, is that the

difference is chiefly due to differences of temperature The bright calcium clouds lie fairly low in the atmosphere of the Sun, and therefore are likely to be at a comparatively high temperature The upper layers of hydrogen giving the dark flocculi may, on the same supposition, be expected to be relatively cooler, and therefore show dark on account of their absorption of light coming from the incandescent photosphere below them

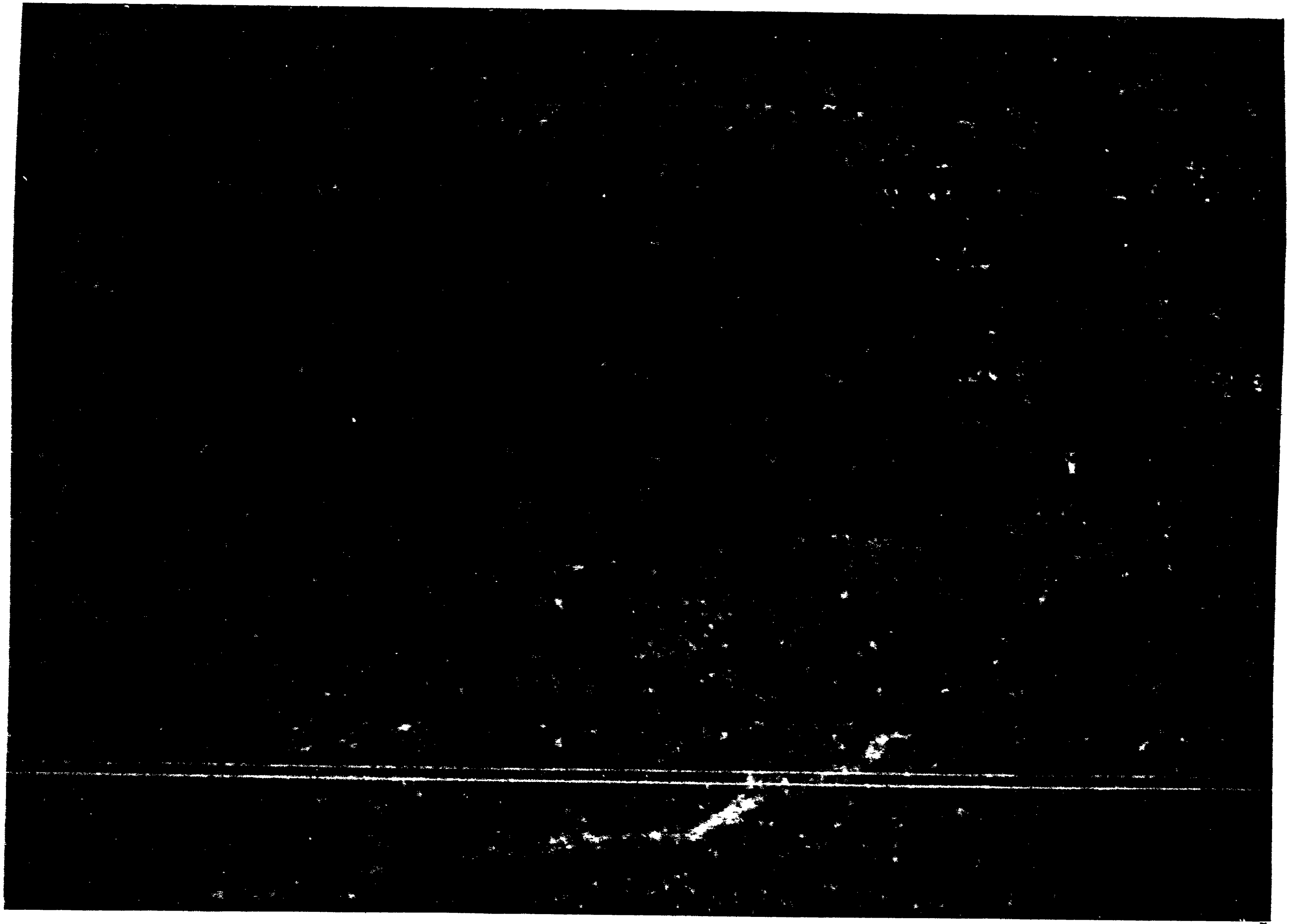
In his early work on the calcium flocculi, Déslandres at Paris had realised that the K line used for the spectroheliograph was so broad that settings on different sections of it might give different results As ordinarily photographed on the body of the Sun, this line is dark and very broad, and



[H Déslandres

SPECTROHELIOGRAM SHOWING RADIAL VELOCITIES

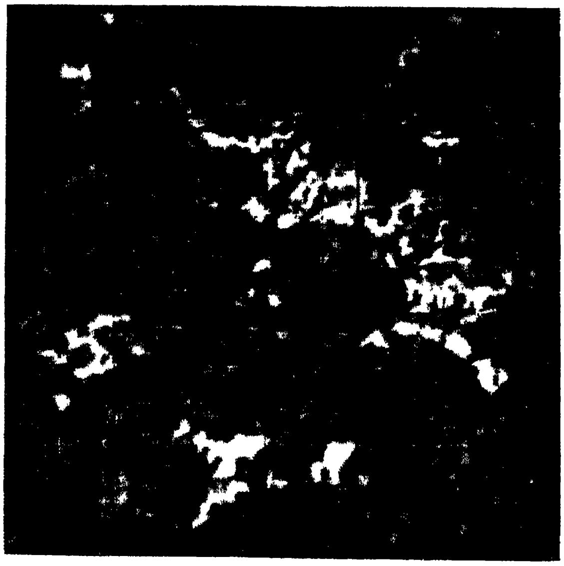
Déslandres, of the Paris Observatory, employs the spectroheliograph in a special way to obtain the velocities of the various solar vapours Instead of making the instrument traverse the solar disc with a uniform, continuous motion, as is ordinarily done, he introduced mechanism to give alternate traverses and stops This gives a series of small pictures of the ultra-violet spectrum, from the distortions of which he can measure the corresponding velocities of the vapours by the application of Döppler's principle



[G E Hale

SPECTROHELIOGRAM SHOWING SOLAR HYDROGEN VORTEX

When the spectroheliogram is taken with the hydrogen line (H_α) in the extreme red part of the spectrum, the flocculi shown are usually dark masses. Frequently these show evidence of vortical motion, indicating some whirling action of the vapours. The direction of these whirls is opposite in the two solar hemispheres, anti-clockwise in the north, and clockwise in the south. These great whirls appear to have a close relation to any sunspots which may be present on the Sun, and a study of this shows that they are the seat of intense magnetic fields, which modify the condition of the vapours in the sunspot nucleus.



[Yerkes Observatory

CALCIUM FLOCCULI, WITH H_1 LIGHT
SEPTEMBER 22, 1903, 3h 40m

Shows the appearance of the calcium clouds when the secondary slit is set on the outer edge of the calcium line H_1, registering only the lower layers at greatest pressure

wherever the spectroscope slit lies over a flocculus, it shows two very narrow bright lines, or, in some cases, a single bright line These are called reversals When a spot is near, or any pronounced disturbance, there is also a secondary dark core, called a double reversal

If now the slit is set on the outer shading of the K line, we get a picture very much resembling the ordinary photographs of the Sun taken without the spectroheliograph When the slit is carefully adjusted on the central bright reversal, the plate shows all the *bright* calcium clouds on the disc Finally, if the instrument is sufficiently powerful, settings can be made on the central dark double reversal, showing all the areas on the Sun which happen to be in the proper condition for giving that effect, that is, the dark flocculi

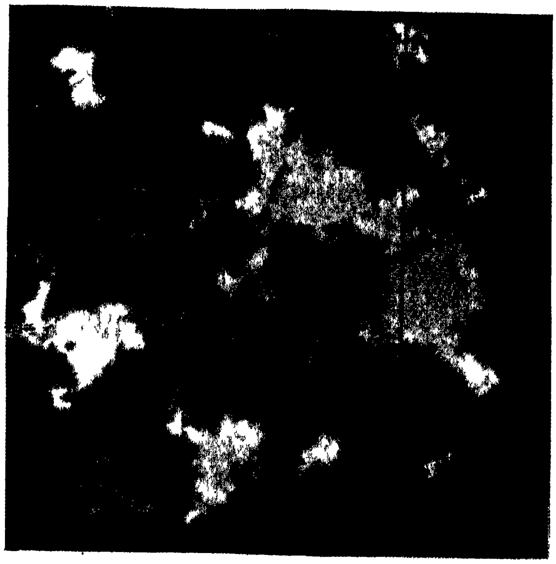
Now from laboratory experience it has been surmised that the width of a spectrum line may be due to the density or pressure of the vapour producing the line, the greater the density, the wider the line So if we set on the outer edge of the broad K line, we are probably utilising the radiation from the gases at the base of the solar atmosphere, where the density and pressure are most considerable When, however, we set on the fine centre line, we are only observing the extremely tenuous vapour of the upper layers of the atmosphere

This idea has been developed, so that from a regular succession of such settings over any disturbed area, we appear to be able to obtain what corresponds to a series of contour maps of the material composing the disturbances in the solar atmosphere

Investigations have also been made with the lines of other elements, for example, iron The results are interesting, but still more powerful instrumental equipment is needed for these narrow lines

Realising that hydrogen being one of the constituents of the *highest* layers of the solar atmosphere, Adams made a series of spectrograms showing the velocity of rotation with several hydrogen lines, at various latitudes along the solar limb The results were extremely interesting, as they showed that the hydrogen atmosphere was rotating quicker than the general layers containing the spots and faculæ The difference amounted to about one degree per day at the equator of the Sun

Further, it was found that the differences of rotational velocity observed at various latitudes for spots and faculæ, did not show in these



[Yerkes Observatory

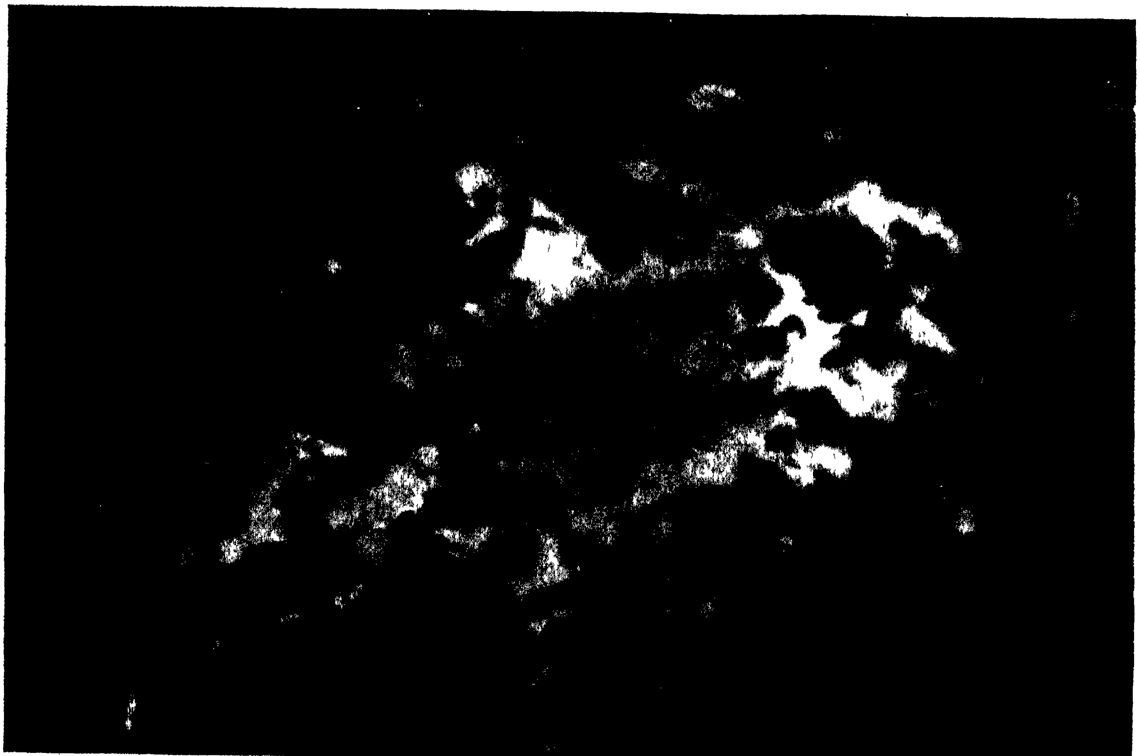
CALCIUM FLOCCULI WITH H_2 LIGHT
SEPTEMBER 22, 1903, 3h 31m

Showing the calcium clouds when photographed with the middle bright portion of the line H_2 Here strata at a medium level are registered, and are much greater in area

measures on the hydrogen atmospheric stratum The velocity was nearly the same from equator to poles In the case of the velocity of the reversing layer, close down to the Sun's photosphere, the difference in rotation period between 0° and 73° solar latitude was about six days, for hydrogen the difference for the same zones was only 1 3 days

Hitherto we have only considered the spectroheliographic records of prominences at the limb of the Sun, and the bright and dark clouds on the disc

Sufficient evidence is now available to make some progress in the correlation of the two phenomena In the case of eruptions there appears to be much evidence for thinking that the explosive prominences are directly associated with the disturbed areas in the neighbourhood of sunspots The type of evidence available is admirably illustrated by the composite spectroheliogram taken at the Yerkes



By permission of] *[The Yerkes Observatory*

BRIGHT CALCIUM FLOCCULI, OCTOBER 9, 1903

This great mass of calcium clouds was observed to be surrounding and overhanging the great sunspot group The details of the spot group show how it is broken up into separate umbræ, round which the flocculi cluster In this type of disturbance, constant change is usually taking place, and series of photographs are taken at short intervals to register the details

Observatory, showing an eruptive prominence in jets from the limb, and a disturbed area on the disc quite close to the origin of the prominence (page 160, bottom)

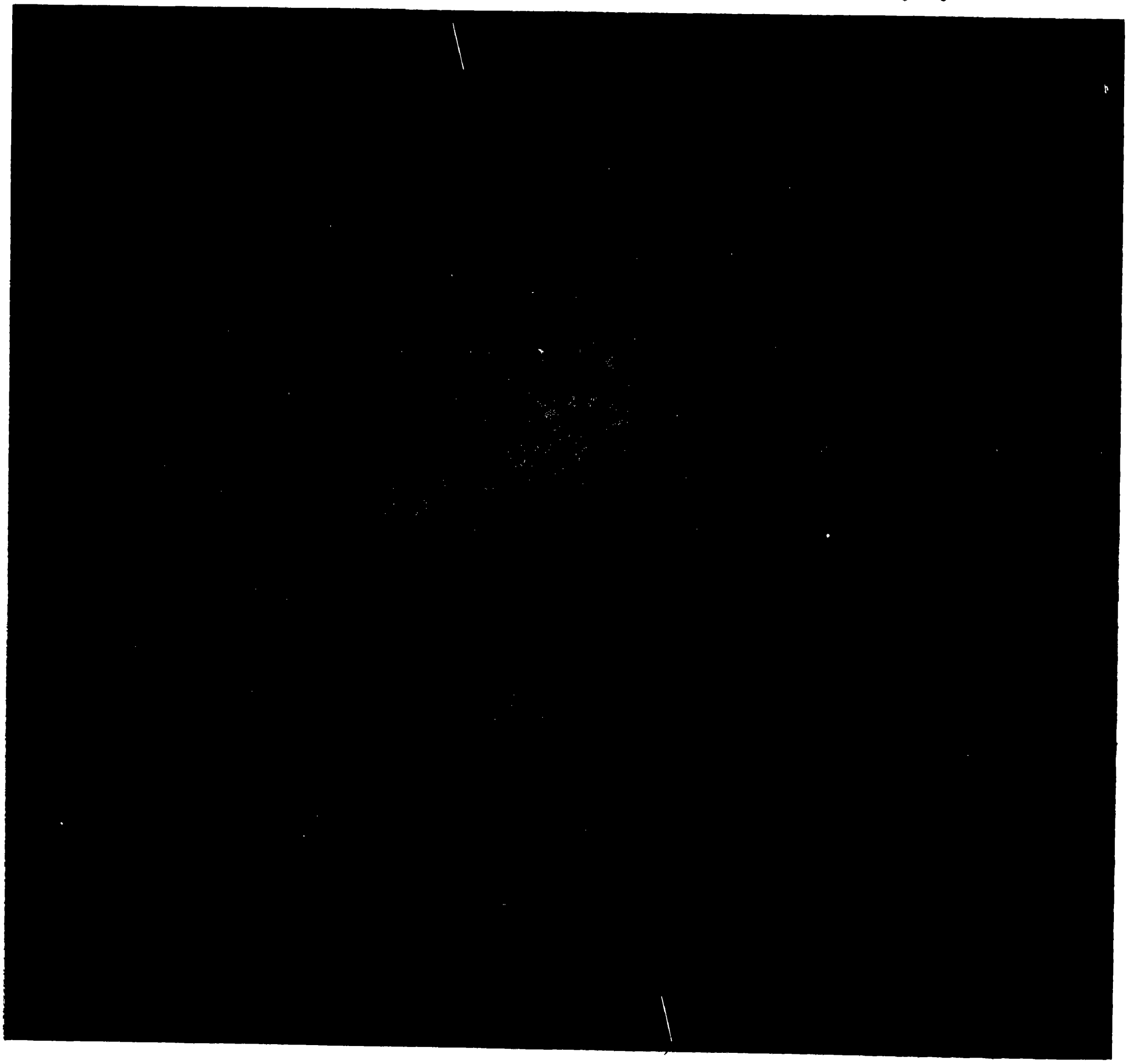
As some dark hydrogen flocculi approach the limb of the Sun they are so frequently found to be associated with prominences at the limb as to suggest that they are really prominences seen in projection against the bright solar disc, absorbing some of the photospheric light, and thus making the area covered by them appear darker than the rest

In 1908 Hale published results showing the peculiarity of very definite vortical structure in the streams of dark flocculi photographed with the H_α line of hydrogen The appearance in some cases is most striking, and when observed in the vicinity of regularly formed sunspots, it assumes so definite a character as to suggest the lines of force seen when iron filings are scattered near the pole of a magnet

Closer inspection showed that these hydrogen vortices are systematically arranged with respect to their rotation. Those found round single spots in the northern hemisphere have their whirls arranged *anti-clockwise*, while those similarly placed in the southern hemisphere are *clockwise*. The appearances distinctly pointed to the existence of solar cyclones or vortices. That this spiral structure is intrinsic to the hydrogen layer is proved by numerous cases where lower the calcium flocculi occupy exactly similar places on the Sun's disc, on the same day, but show no trace of vortical structure.

The discovery of vortex structure led Hale to suspect that these regions would be sources of magnetic phenomena, due to the rapid rotation of charged particles in the vortices.

A ready method of putting the matter to a positive test lay in the discovery by Zeeman that if



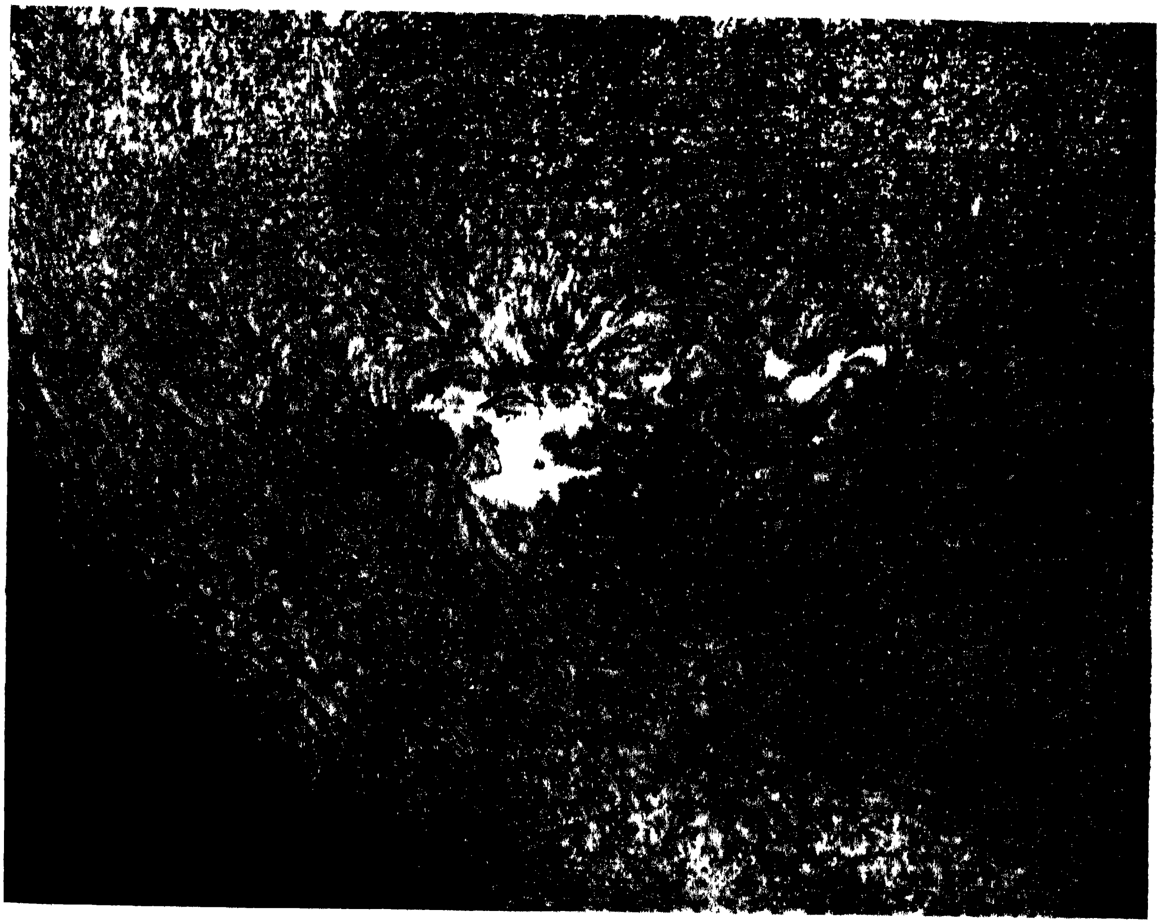
[J. Evershed

CALCIUM FLOCCULI AT TIME OF SUNSPOT MAXIMUM

Spectroheliogram of the solar calcium clouds taken near the time of maximum solar activity, August 10, 1917, at the Kodaikanal Observatory, India. Both bright and dark flocculi are shown. The inclination of the bright masses to the western side is very clearly indicated in both hemispheres. Many of the flocculi are seen to have sunspots near their extremities, in some at one end only, in others at both ends. Note how the thin dark flocculi meander among the bright masses, and in general they appear to be inclined in the same direction to the west.

a light source, emitting under ordinary conditions a spectrum consisting of single lines, were placed in a strong magnetic field, the single lines were replaced by multiple components, the number and separation of which depended on the direction and strength of the magnetic field

For a number of years previously peculiarities had been observed in the spectra of sunspots, for which no satisfactory explanation had been adopted Some of the lines were widened, others doubled, and various other modifications from the appearances of the lines in the ordinary Fraunhoferic spectrum had been classified It appeared that these new indications of the possible presence of rotating material in the vicinity of the spots might explain the cause of some of the differences



[R A S

SOLAR VORTICES ROUND SUNSPOTS

An enlarged photograph showing the details of the vortex streams round the three large sunspots From a study of such pictures it has been determined that these vortices produce magnetic fields in the sunspot centres, modifying the spectrum lines of the vapours existing in the spots Also that the Sun itself acts as a feeble magnet

This was actually found to be the case, and it was shown that the double lines, for instance, observed in sunspot spectra, were produced by the radiation having been under the influence of a magnetic field Also, by comparison with standard magnetic fields in the physical laboratory, it was possible to artificially produce doublets, &c , of exactly the same separation, and thereby obtain accurate measurements of the strength and direction of the magnetic fields in the sunspot areas

The great success of these observations of magnetic forces in sunspot vortices led to the design of more powerful apparatus, and during the years after 1909 a huge new spectroscope and spectroheliograph equipment were constructed at the Mount Wilson Observatory in California, having a telescope

150 feet focal length, and a spectrograph 75 feet long With this it has been possible to determine that the Sun itself acts like a magnet, that is, at all parts of the Sun, as on the Earth, a compass needle would be constrained in a certain direction, pointing to the magnetic pole Hale was also able to prove that the Sun's magnetic poles do not coincide with the poles of the axis of rotation

Still further improvement of the apparatus has enabled the American observers to detect faint disturbances of the outer surface layers of the Sun's atmosphere which appear to be far too small to produce anything in the nature of the commotion found even in a small sunspot of the usual type But, taking the view that any signs of cyclonic or vorticose rotation in the solar material might give rise to small magnetic effects, special search has been made for them Only a short time ago Hale was able to announce the detection of what he calls *invisible sunspots*, a somewhat paradoxical name, but indicating that disturbances were present giving effects of similar nature to those shown by ordinary sunspots, but so weak that they did not develop so far as to become visible

To obtain such results it has been necessary to take special precautions against the possibility of changes of temperature, or small vibrations in the apparatus Advantage has also been taken of the immense improvement in the quality and speed of photographic plates in recent years Some of the work would not have been possible with the plates of twenty years ago Now all parts of the spectrum can be photographed with almost equal facility, from the extreme red to the ultra-violet Some of the spectroheliograms are taken in the light of hydrogen (H_α), at the red end of the spectrum, while others require to be taken with the ultra-violet light K of calcium, far away at the opposite end

Drawing by] [*Scriven Bolton*

THE EVENING STAR

Seen in the deepening twilight of the western sky, Venus forms one of the most beautiful spectacles that the Heavens afford No other planet or star approaches her in splendour, and she attracts the attention of the least observant

CHAPTER IV

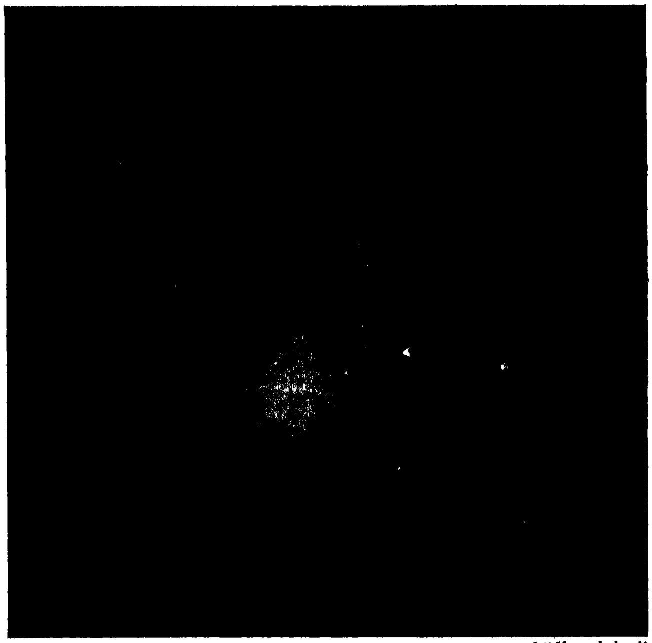
ZODIACAL LIGHT AND THE INFERIOR PLANETS

By W F Denning, F R A S

THE names of celestial discoverers in ancient times are nearly all unknown, and so are the dates when their discoveries were made Though certain objects and phenomena are supposed to have owed their detection to comparatively modern observers, they must have been seen long before by people whose records are lost or who probably mistook their meaning and significance and did not realise the importance of what they saw The discovery of the Zodiacal Light has been attributed to J D Cassini, who lived in the middle of the Seventeenth Century, and who was, after Galileo, the leading astronomical observer of that time Childrey, in a work he published in 1661, called the notice of astronomers to the Light which he had observed in February and March for several years

But a long time before this, viz., at the end of the Sixteenth Century, the celebrated Danish observer, Tycho Brahe, detected the apparition of the Zodiacal Light and had mistaken it for vernal evening twilight of unusual character.

The Light, however, is not a modern innovation, and must almost certainly have been noticed by ancient observers, though they probably considered it an unimportant appearance, depending upon a mere condition of the air. The Chaldean Shepherds must have frequently remarked it during their ardent contemplations of the stars, but it is curious that the Light apparently received no proper mention and record. If the phenomenon really dates its first recognition from ancient times all historical mention of the fact is lost, like that of the discovery of Mercury, of the Aurora Borealis and other objects which are palpable enough to modern eyes. Even the significance of meteors, startling as they sometimes were in their vividly luminous aspects, were in former days scarcely given attention, and were allowed to pass without anything beyond mere verbal remark. Considered to be trivial and temporary objects, purely atmospheric in their origin and character and due to inflammable gases there, the old observers paid little heed to such phenomena, though they contemplated the stars with keen interest and intelligent enthusiasm, and rightly conjectured their primary importance and seemingly everlasting stability in the scheme of Nature.

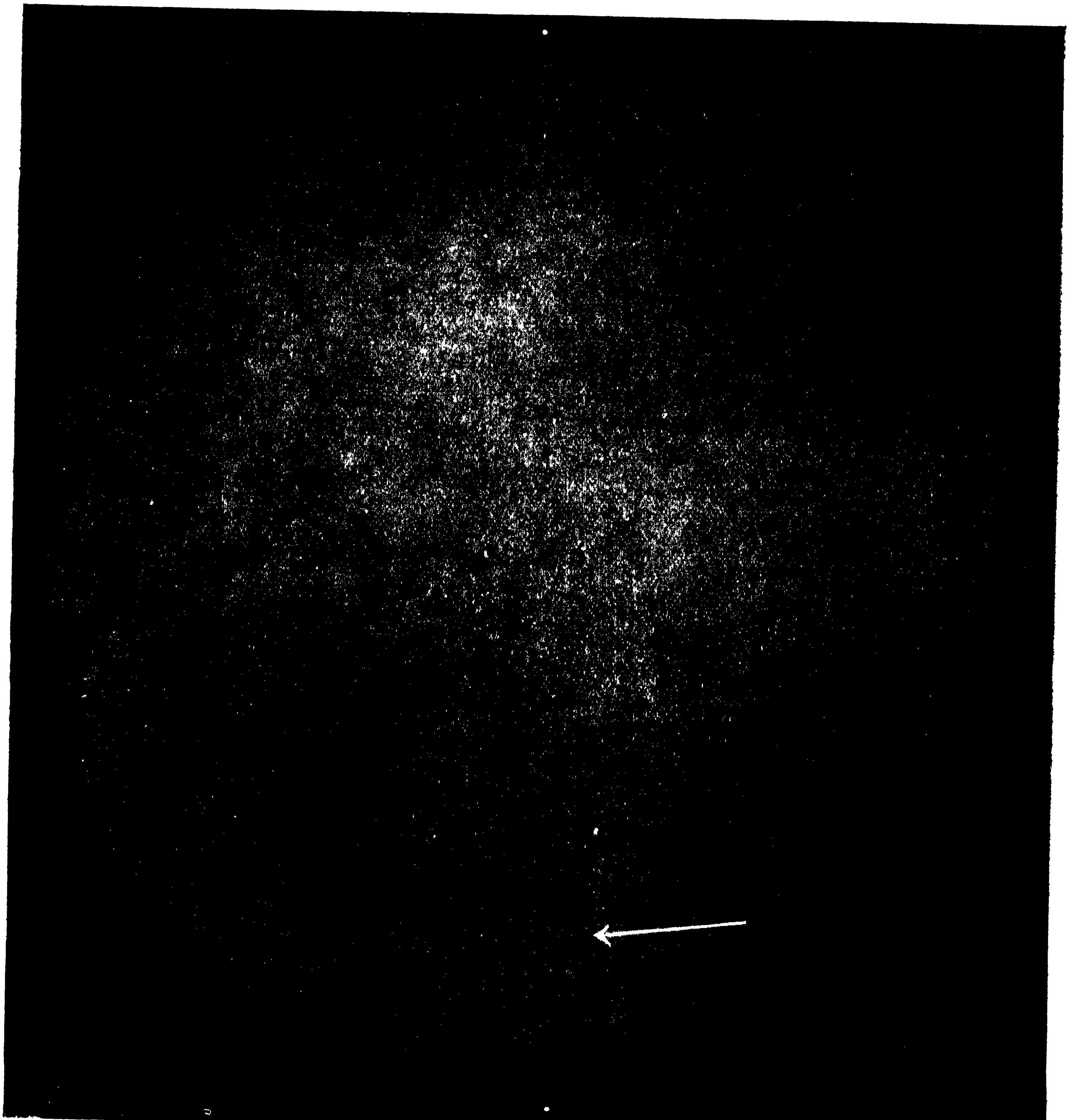


From] [*"Knowledge"*

PHOTOGRAPH OF THE ZODIACAL LIGHT

Very few photographs have ever been taken of the Zodiacal Light. This is due to its extremely feeble luminosity, which necessitates very long exposures with ordinary lenses.

Humboldt says that he found the strength of the illumination increase astonishingly as he approached the equator in South America and in the Pacific. In certain parts favourable to observations of this nature he described the brightness as sometimes surpassing that of the luminous sections of the Milky Way between Argo and Sagittarius, and the region of Aquila and Cygnus. He considered that the variations which occurred in its intensity depended not so much on the observer's station as upon changing conditions originating in, and affecting, the phenomenon itself. In tropical regions the Light is strongly presented, and it is in such places that the study of its forms, intensity, extent, and visibility should be conducted with all the skill and energy required to ensure success. Some of the earlier observers—Laplace, Schubert, Arago, Biot, and others—contended that the Zodiacal Light had its origin in a vaporous, flattened ring situated between Venus and Mars, and Humboldt considered this the most plausible hypothesis to account for the phenomenon. He termed it the "Ring of the Zodiacal Light." Sir John Herschel, however, objected to this explanation, and said: "I cannot imagine upon what grounds Humboldt persists in ascribing to the Light the form of a ring encircling the Sun." Herschel, in his well-known "Outlines of Astronomy," described it as "a cone of lenticularly (*i.e.*, lens) shaped light extending from the horizon obliquely upwards and following the course of the ecliptic, or rather that of the Sun's, equator. The apparent angular distance of the vertex from the Sun varies according to circumstances from 40° to 90°, and the breadth of its base, perpendicular to its axis, from 8° to 30°. It is extremely faint and ill-defined, at least in this climate, though better seen in tropical regions, but cannot be mistaken for any atmospheric meteor



From] TRANSIT OF MERCURY 1914, NOVEMBER 7. [" *Knowledge* "

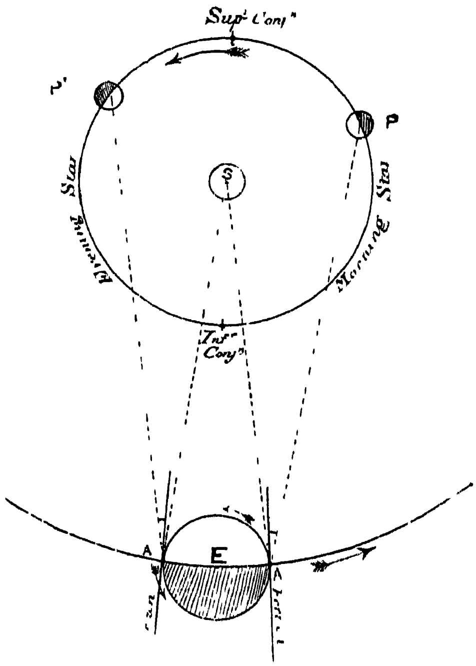
Venus, when in transit across the face of the Sun, appears as quite a large object, and can be seen with the naked eye through a dark glass Mercury, however, is not only a smaller body but is much farther from us Consequently, the transits of this planet can only be observed through a telescope All that is then seen under the best conditions is a perfectly smooth black disc standing out crisply against the bright background of the solar surface On this photograph, taken under poor conditions at Greenwich, Mercury is seen as a minute ill-defined black spot near the middle of the lowest portion of the Sun's disc

or aurora borealis. It is manifestly in the nature of a lenticularly formed envelope, surrounding the Sun and extending beyond the orbits of Mercury and Venus, and nearly, perhaps quite, attaining that of the Earth."

It is well that in recent times mankind has cultivated the scientific spirit and acquired the habit and appreciated the necessity and importance of careful observation. Thus the great significance attached to many natural events has been proved and their special characters understood and acknowledged, whereas through the earlier ages of the world's history little or nothing was attempted with regard to observing and recording them in detail with a view to solving the many interesting problems which the face of the heavens offered for solution.

The Zodiacal Light may be described as a glowing band, broad at the base near the horizon and getting fainter and narrower as it stretches obliquely upwards.

In the spring months it is conspicuously displayed after sunset on moonless evenings, and in the autumn it is observable before sunrise. It flows over an extensive area, and may sometimes be traced from near the east or west horizon to a



DIFFERENT POSITIONS OF VENUS

As seen from the Earth, Venus passes alternately on the near and far sides of the Sun, and she is then said to be, respectively, in Inferior and Superior Conjunction with that body. When at her greatest apparent distance east or west of the Sun, she is said to be in Elongation. She then appears high in the sky though the Sun is below the horizon.

From] ["Knowledge."

PHOTOGRAPH OF THE ZODIACAL LIGHT

Long exposures are not possible in photographing this object, since its position in the western sky causes it to set quite soon after it first becomes visible in the twilight.

considerable altitude in the southern sky. It varies in intensity and visibility, being sometimes a striking phenomenon and at other times scarcely discernible. Its appearance is evidently subject to variations dependent on the condition of the atmosphere, and possibly on other causes.

The Light is now believed to be a celestial feature, and has been explained on the view that it represents the diffused light reflected from myriads of meteoric particles revolving in streams round the Sun. At first consideration, this explanation might be thought insufficient owing to the fact that meteoric systems are inclined at all angles. But we must include the minor planets, of which an immense number probably exist, though not more than about 1,100 are known, also the comets of short period and the majority of meteoric systems which do not move in orbits that are greatly inclined. No doubt the space over which our Solar

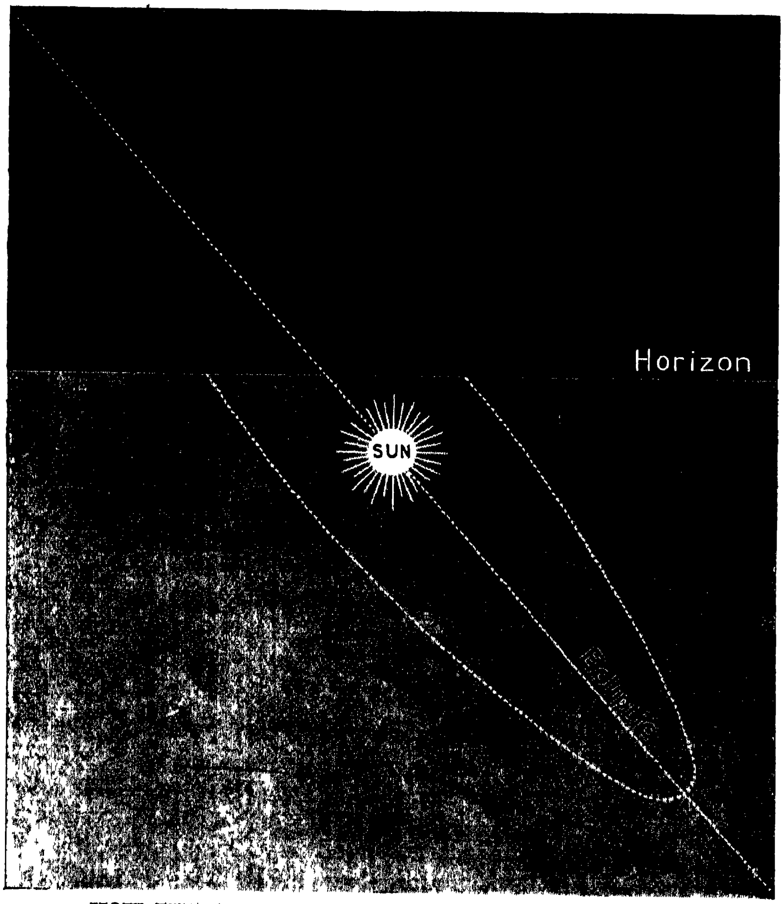
System extends is rich in small planetary bodies, and the action of the large planets through past ages has been to draw smaller objects into paths having little inclination In fact, the orbits of the minor planets, periodic comets and meteors must approximately correspond to the direction of the Zodiacal Light, and the latter phenomenon simply presents a feature which we might naturally expect

The cosmic origin of the Light has been disputed by several astronomers, but the features of its appearance and position greatly favour, if they do not absolutely prove, that the object has its derivative source far outside the Earth's atmosphere and results from solar reflection on myriads of planetary atoms mainly distributed in directions nearly conformable with the plane of the Sun's equator

From] [*"The New Heavens"*

A LENS-SHAPED NEBULA

Many spiral nebulæ present their edges to our view, and so are seen "in section" rather than "in plan" It is always noticeable that they are, like a lens, thicker in the middle than at the edges, and there seems a certain analogy between this distribution of matter and that presumed for the Zodiacal Light in the Solar System

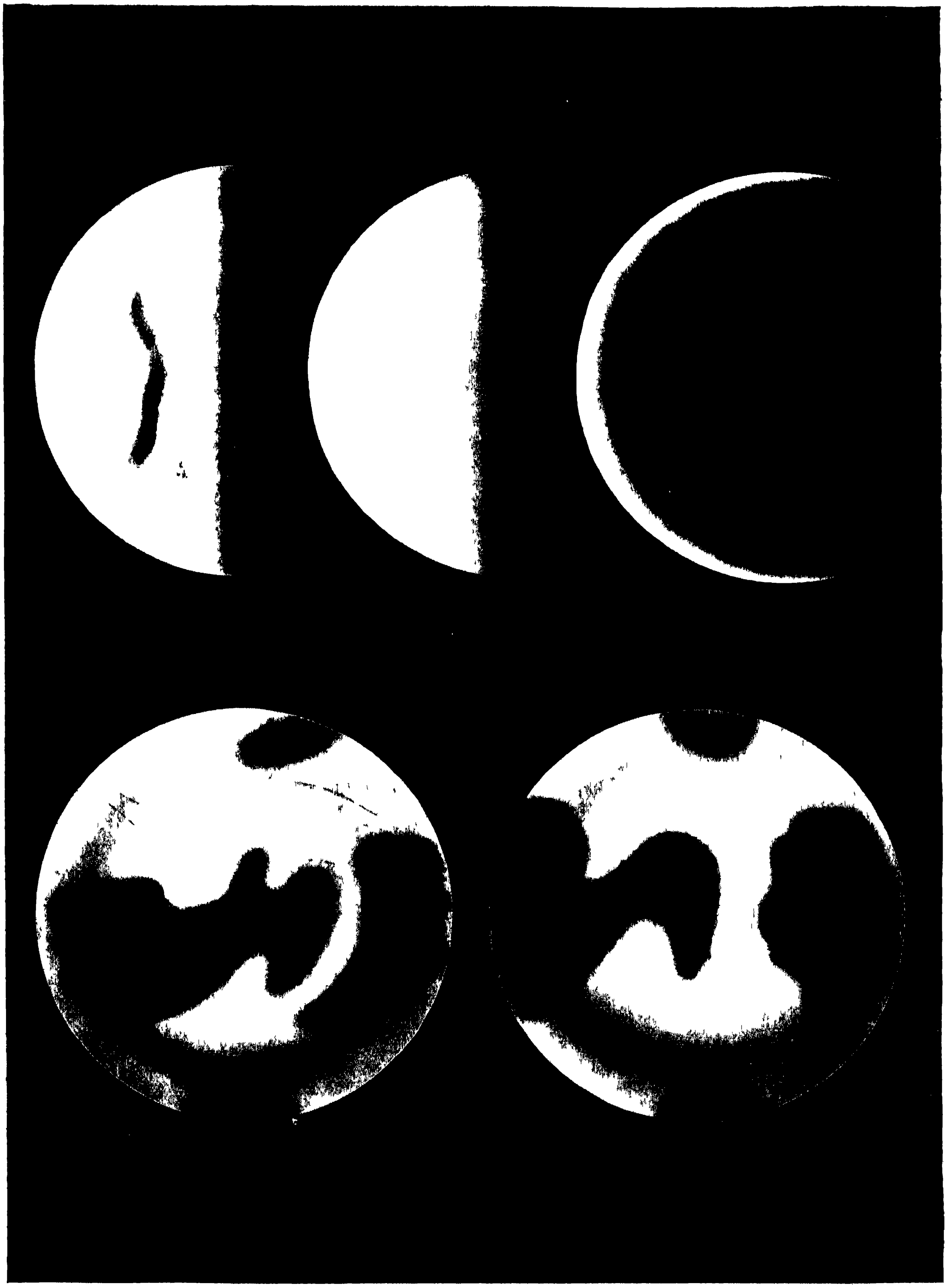


HOW THE SUN IS PLACED IN THE ZODIACAL LIGHT

The Zodiacal Light extends along the Ecliptic on both sides of the Sun, which is centrally placed in it We can only observe one end of the Light at any one time, the other being, with the Sun, below the horizon The portions of the Light seen in the evenings and mornings are thus the opposite ends of one great continuous formation

It has been alleged in opposition to the idea that the Zodiacal Light is a celestial production that it has been sometimes viewed to the best effect in a somewhat hazy atmosphere It was better defined on a November morning as seen from Clapham by Fasel than he had viewed it in a far more favourable atmosphere in Switzerland On the mornings of December 3 and 4, 1916, the Light appeared unusually brilliant to the writer at Bristol, though the atmosphere was not favourable for such an observation

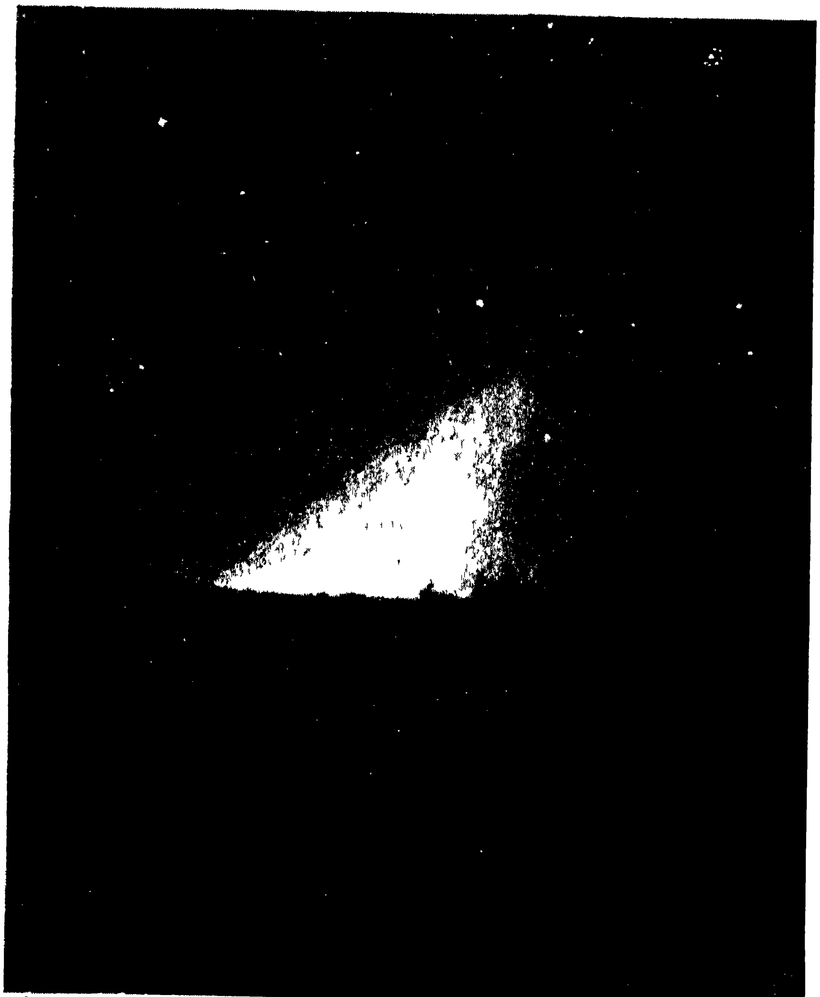
The extremities of the cone extended to the stars in the Sickle of Leo or about 100 degrees westward from the Sun, but from numerous observations at the same place it appeared that the Light varied considerably, and was sometimes seen to extend much farther than at others The testimony of different observers appears to be consistent in proving the remarkably variable



SOME OLD DRAWINGS OF VENUS.

These drawings were made in the Eighteenth Century, in the early days of the telescopic study of Venus The three upper views are due to Schròter and show irregularities at the " cusps " and in the " terminator," or sunset line, of the planet These Schroter attributed to the presence of mountains and valleys on Venus, but his estimates of their probable height and depth are now known to have been erroneous The two lower pictures show the large dusky patches observed by Bianchini, and believed by him to be seas Similar markings, of a less definite character, have since been seen and drawn by many observers

character of the Light. Its extent and visibility are liable to considerable alterations though its general form is similar. Sometimes a striking feature, at other periods, with conditions apparently the same, it may be feebly discernible. It seems highly probable that the illuminating power of the phenomenon changes from some inherent causes, and differences in our atmosphere must account for many discordances; but we can hardly explain in this way all the peculiarities of aspect which sometimes at short intervals the Light displays.



After a Drawing] [*By M. Eiffler*

THE ZODIACAL LIGHT, SEEN IN THE TROPICS

This illustration gives a fair idea of the general shape and distribution of luminosity in the Zodiacal Light. The central and lower portions of the "cone" are always the brightest, and have been observed to be more luminous than the brightest portions of the Milky Way. The Light fades towards the edge of the cone and merges into the sky background more gradually than indicated in the picture.

Humboldt, who watched the phenomenon from foreign countries, describes its aspect as like "a pyramidal beam," and noted its surprising alterations of appearance. At stations where a clearer atmosphere and better climatic conditions generally prevail the Light is stronger and admits of more successful observation.

As already stated, different authorities vary in their opinions as to the nature of the phenomenon. Wood thought it simply a meteorological effect, and says: "Masquerading through the constellations of the Zodiac as though it were a celestial object, we are confronted with what is probably nothing more important than a column of atmospheric dust feebly illumined by the action of the vertical currents of the Earth's permanent magnetism in their passage through the atmosphere into space, directed by solar repulsion."

Lowe, at Nottingham in February, 1850, remarked that the Light was more brilliant on one night than it had been for the previous seven years, showing pulsations of greater or less brilliancy in periods of thirty seconds, so variable as to be almost extinct at times.

Guillemin remarked: "It is not purely meteorological, since its participation in the diurnal movement, its visibility in regions of the Earth over distances from each other, and, lastly, its nearly invariable inclination along the ecliptic indicate sufficiently that the cause which produces such appearances lies outside our atmosphere in the celestial spaces."

Proctor says of the Light that it presents that faint tinge of pink which has been recognised in the corona "It has been observed to fluctuate in brightness, and to be traversed by flickerings analogous to the aurora This glow obeys all the usual laws observed in the motion of all celestial bodies It rises and sets precisely as the stars do, and presents those peculiarities which force on the astronomer the conclusion that it is an extra-terrestrial phenomenon It is a ring of meteors outside the Earth's orbit revolving round the Sun "

The above may be taken as samples of the views held by different writers, and a large number of other references might be made Observations of the Light are really abundant, but most of them lack the systematic character, fullness and accuracy of detail which are essentially required One of the most diligent students, the Rev G Jones, published at Washington in 1856 a book on the subject, in which he gave 356 plates of the Light as he observed it The Zodiacal Light cannot be described as a usually conspicuous or attractive phenomenon, though it is often very distinct and striking at places specially favouring its visibility, and it invites the earnest contemplation of the appreciative student of nature The fact is that this light is not one of ostentatious character It may not arouse enthusiasm in the soul of the individual who delights in brilliant spectacular effects But it speaks tellingly to the deeper student of celestial wonders who regards it as a beautiful object and an awe-inspiring one, for in its far-reaching phosphorescence he mentally recognises myriads of planetary objects revolving around the Sun and pursuing orbits varying considerably in distance, though not greatly inclined to the plane in which the Earth itself revolves

From] [*"Knowledge"*

PHOTOGRAPH OF THE ZODIACAL LIGHT

No ordinary photographic lens being rapid enough for the purpose it was necessary to use a lens which, though giving great light grasp, was defective in other ways This accounts for the distorted shapes of the star images far from the middle of the picture on this and pages 179 and 181

From] [*"Knowledge*

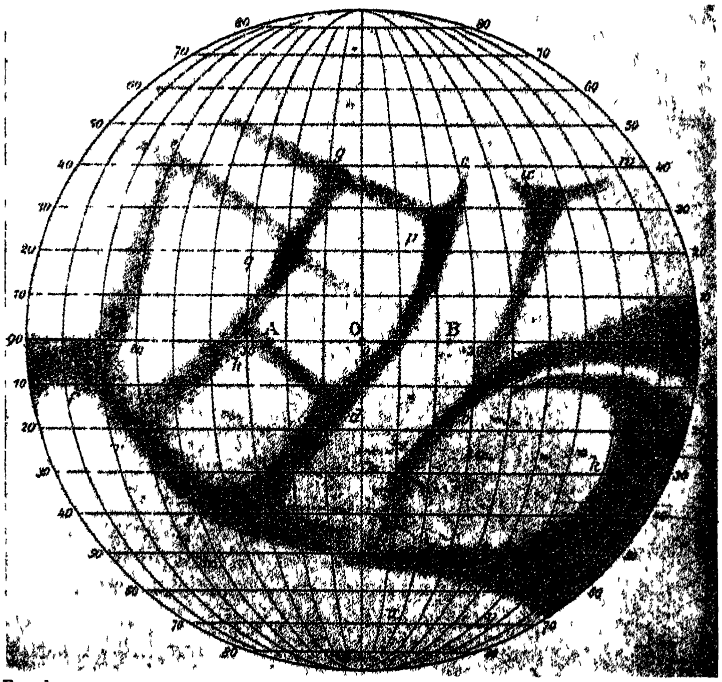
PHOTOGRAPH OF THE ZODIACAL LIGHT

It is only under exceptionally good atmospheric conditions, and in fairly low latitudes, that satisfactory photographs of such a faint object are obtainable The above picture was secured at the Lowell Observatory, in Arizona, at a height of over 7,000 feet

When a person recognises this light and endeavours to describe it with precision, he finds himself confronted

with a difficulty The object spreads over an extensive area and its boundaries are indefinite, in fact, the brighter parts fade gradually and imperceptibly away into the general tone of the sky We can only roughly estimate, therefore, where the terminal lines are placed It is the same with all large faint nebulosities An observer looking at the feebler portions is apt to see them flash and to believe that pulsations and waves of luminosity run through them This, however, results from the inability of the eye to retain a steady hold or grasp of the faint object It is a case of momentary glimpsing These apparent rapid changes in luminosity are not temporary variations in the thing itself, but are mere visionary sensations, due to the extreme tenuity of the light which is hovering on the border line of visibility and non-visibility

The "Counter Glow"—This represents a feeble glow sometimes seen in the sky in a position opposite to the Sun, and obviously beyond the Earth's orbit It has been found to be of an elliptical form, and averaging some twenty degrees in diameter



From] [Astronomische Nachrichten, No 2944

A MAP OF MERCURY

Few observers have been able to see markings on Mercury with sufficient definiteness to be able to recognise them with the certainty necessary for making a map of the planet's surface However, the late Professor Schiaparelli, observing in the clear sky of Milan, was able to do so, and the map shown above was drawn by him

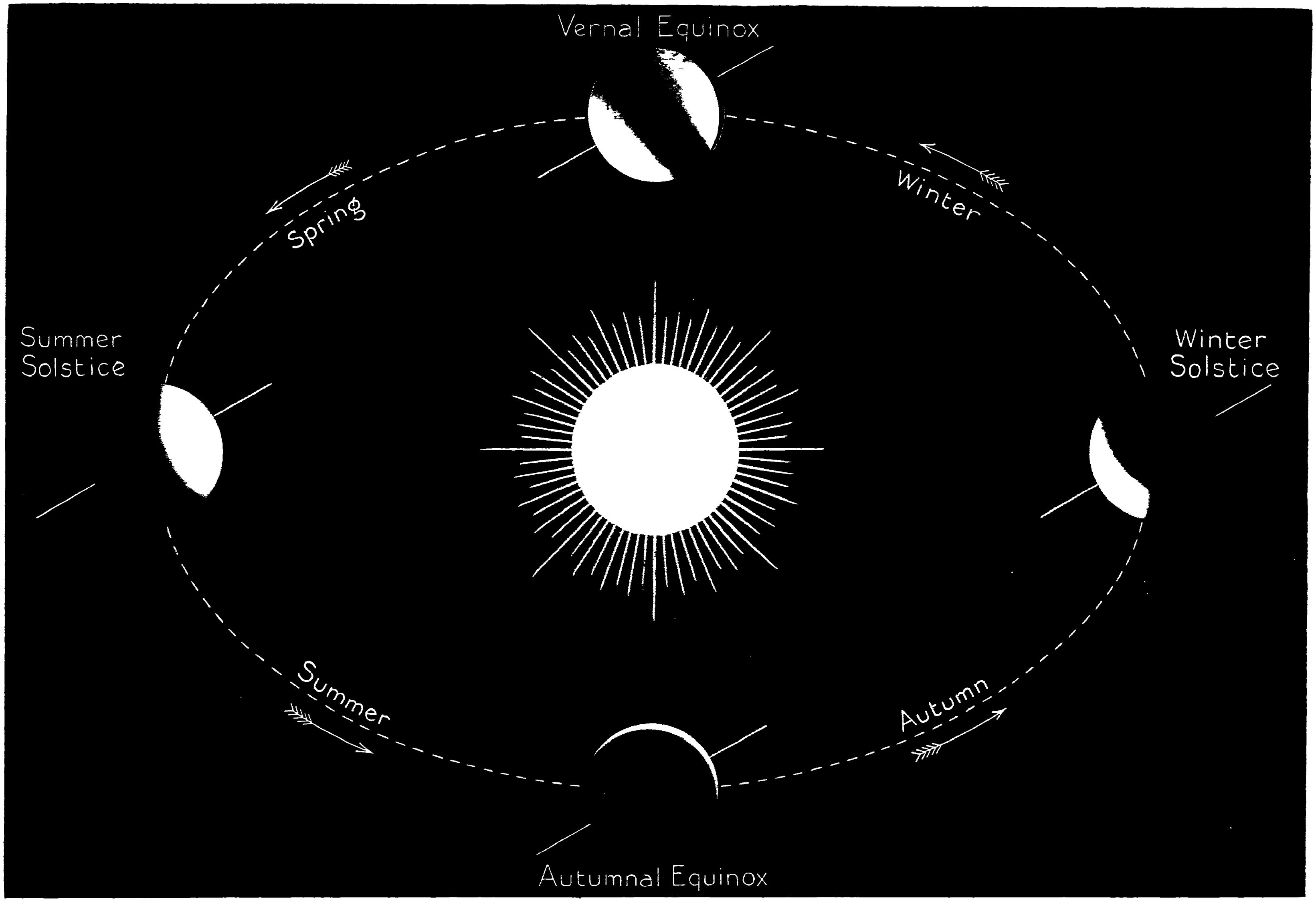
In September and October it has been observed diffused over the region of Pisces, and also near the end of January in Cancer Observations of this feature are not very numerous, and they give no certain clue as to the cause producing it, but it is probably due to the same cause as the Zodiacal Light, viz, the reflection from meteoric and planetary particles moving in that part of their orbits outside the Earth's position An electric origin has also been discussed and the idea has been held that it represents a band of hydrogen and helium repelled from our globe by solar influences

Another theory is that it is due to a swarm of meteors which accompany our globe in its orbit around the Sun, and continually retains the same position on the outer side of an imaginary line passing through the Sun and Earth

The Supposed Planet Vulcan —More than half a century ago it was thought highly probable that a planet existed revolving in an orbit between Mercury and the Sun Various observers on different dates had seen dark, roundish spots in transit across the Sun's disc, and it was said they exhibited rapid motion, and a planetary aspect which could only be explained on the inference that they were transits of an unknown orb

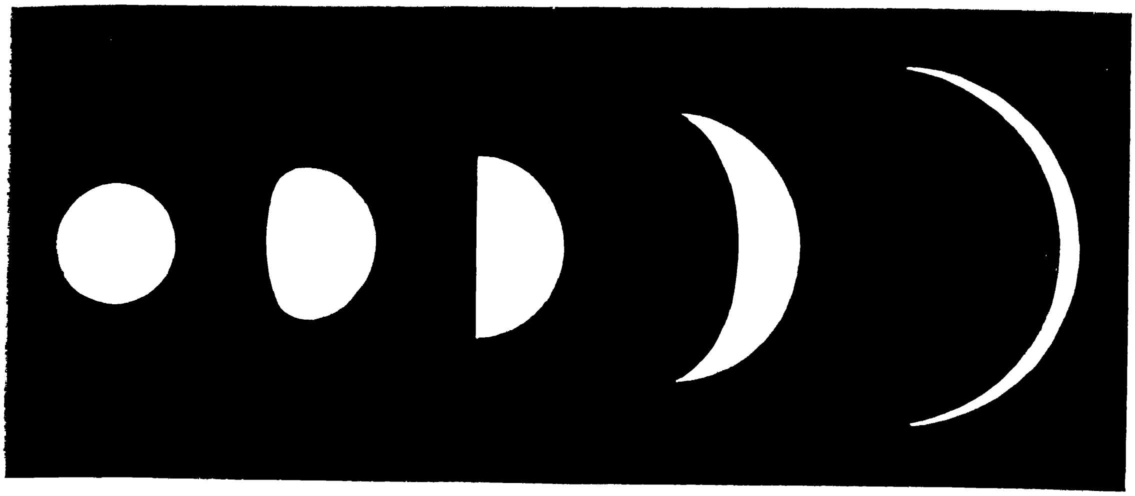
Le Verrier had also announced that certain perturbations occurring in the motion of Mercury indicated that a disturbing planet or possibly a zone of asteroids existed in the space separating Mercury and the Sun

The observations made were by no means perfect, and they apparently were inconsistent when critically compared, but from the data available mathematicians endeavoured to deduce the orbit, and the suspected planet was provisionally named "Vulcan" Le Verrier computed for it a period of twenty days The probable date of the next transit was given and careful watch was maintained



A THEORY OF THE SEASONS OF MERCURY

In order to account for the apparent direction of rotation of certain markings observed by him on Mercury at the end of the Eighteenth Century, Schroter suggested that the axis of the planet was inclined considerably to its path round the Sun, as is the case with our own Earth The effect of this would be to produce Seasons, and these would, in the case of Mercury, be of very unequal length and temperature, owing to the great variations in the planet's distance from the Sun The observations of Schroter have not been confirmed, and we are still in ignorance as to the exact inclination of Mercury's axis

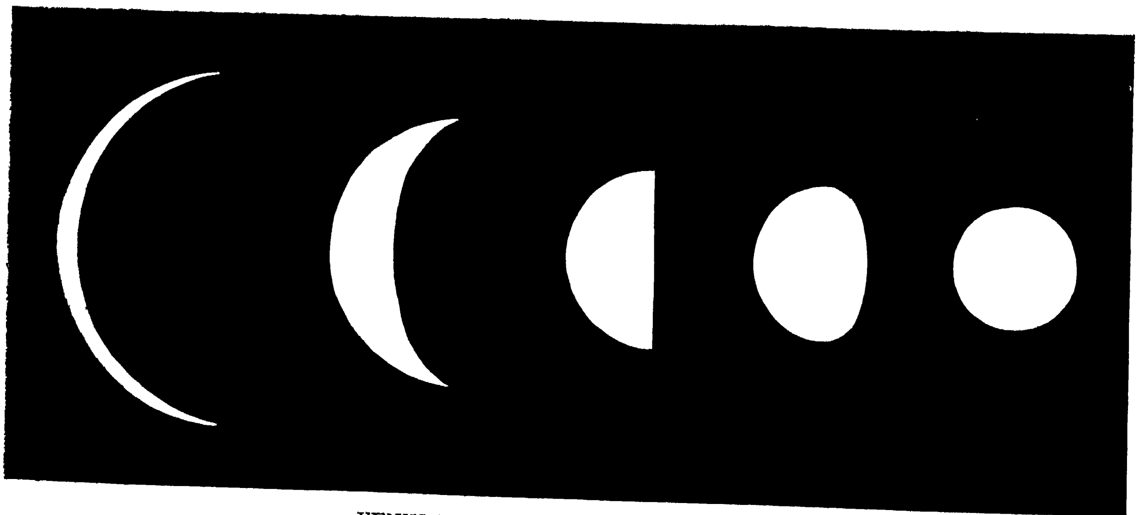


VENUS APPROACHING THE EARTH

When Venus first comes into the evening sky she appears close to the Sun and shows a nearly full disc in the telescope As she approaches us she appears larger and less fully illuminated, and, up to the time when she is a "half moon," is seen farther from the direction of the Sun Thereafter she seems to approach the Sun again, becoming meanwhile an ever larger but thinner crescent The proportions in this and the succeeding diagram, however, are not drawn to scale

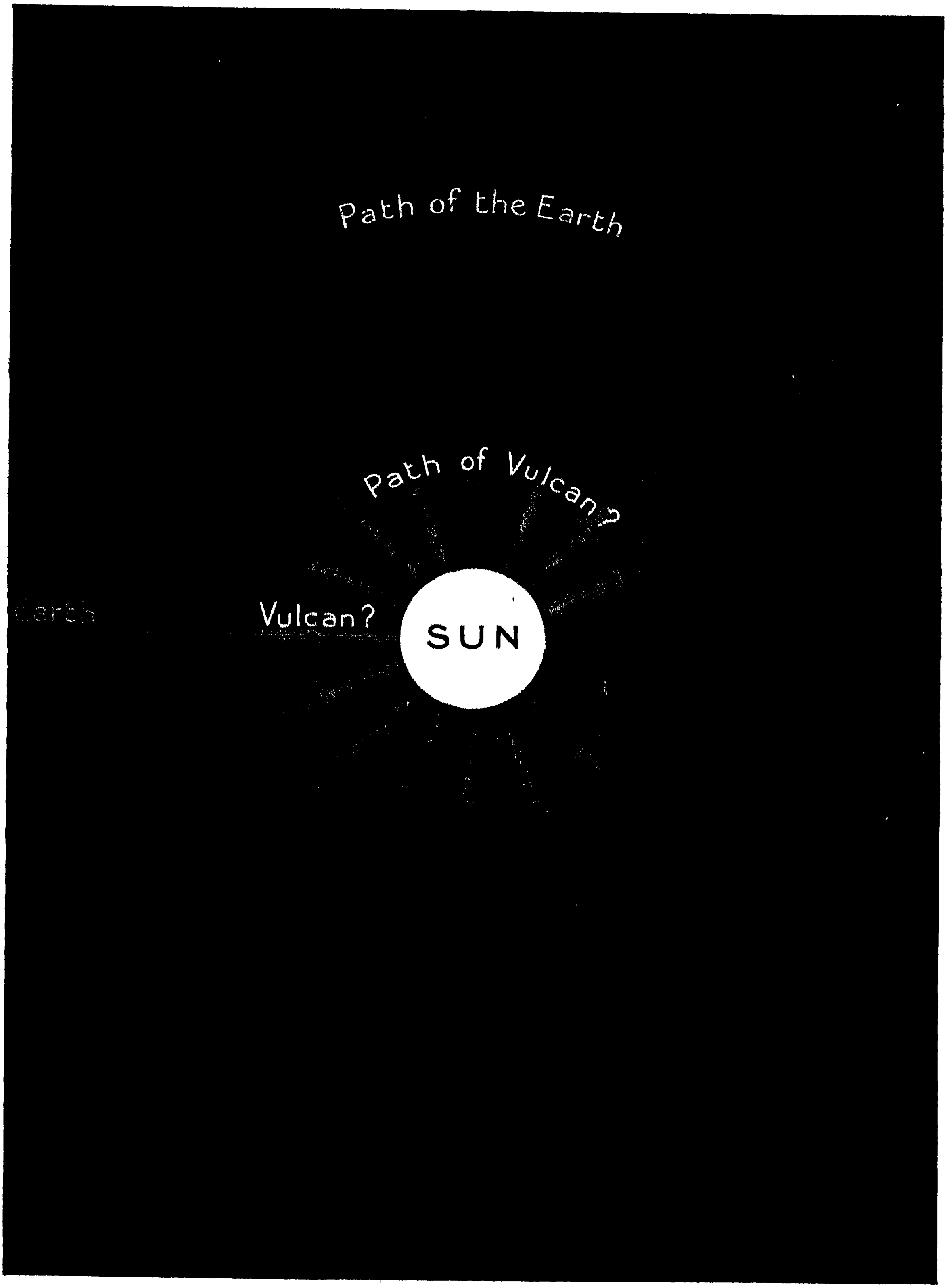
of the Sun's disc at the important time, but nothing was seen of a strange spot on the solar surface For several years the supposed planet was made the object of systematic searching during the months of March–April and September–October, which were regarded as the most likely periods for it to transit the Sun Absolute failure attended all the efforts made to obtain another glimpse of the missing orb

During several total eclipses of the Sun the region near the hidden solar orb was surveyed with good telescopes, and on the occasion of the eclipse of July 29, 1878, it was announced by Watson and Swift that one, if not two, new planets had been detected In any case starlike objects had been found in places which did not agree with those of any known bodies After a good deal of investigation and controversy, however, nothing could be proved from the new observations



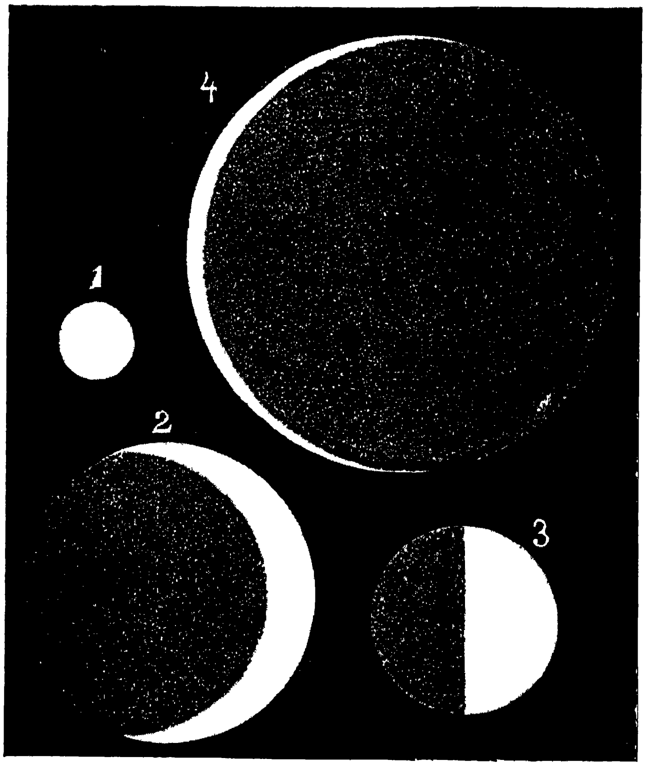
VENUS RECEDING FROM THE EARTH

After passing close to the Sun (apparently), when she is at her nearest to us, Venus, after being lost for a few days in the solar rays, reappears to the west of the Sun and becomes a morning star, visible just before dawn Thereafter she passes through the same series of changes in a reversed order, finishing up as a small fully lit disc close to the Sun



"VULCAN," THE MYSTERY PLANET.

About the middle of the Nineteenth Century much excitement was created in the astronomical world by the announcement that a dark body, of planetary appearance, had been seen in transit across the Sun's disc Attempts were made to calculate the orbit of the supposed new planet, which many astronomers seriously believed to exist within the orbit of Mercury However, it has never been seen since its first announcement, and it is generally believed by astronomers to be non-existent During the past fifty years the Sun has been photographed almost daily, but no dark celestial body, other than the usual solar spots, has ever been found on the plates



THE VARIOUS PHASES OF VENUS

We never obtain a satisfactory view of the surface of Venus when she is at her least distance from us, for at such times she turns very little of her illuminated side towards us, appearing as an exceedingly slender crescent (as at 4 in the illustration) When she appears fully illuminated (as at 1) she is more than six times as far away Consequently our best views are obtained at epochs corresponding to phases 2 and 3, when the planet is half illuminated or appears as a thick crescent She is at her brightest between the phases 2 and 3, and then casts distinct shadows on a bright surface at night

Of recent years no fresh incidents have transpired to corroborate the existence of Vulcan, and as a natural consequence the belief that such a planet has any objective reality has been generally abandoned It could not possibly have escaped all the observations of late years Vulcan, therefore, in the absence of any further evidence, must be regarded as a planet of fiction rather than of fact The theory of his existence was built up on doubtful and imperfect observations, which were never entitled to much weight They have now been conclusively negatived, and in the future the story will be regarded as one of the temporary romances or myths of Astronomy, like the satellite of Venus, the active volcanoes on the Moon, and the double canals on Mars

Any mystery that may have been attached to the above objects has long since been removed, for they were all easily explained as due to errors of observation or of judgment A Frenchman, Dr Lescarbault, was chiefly responsible for the affirmative belief in the hypothetical Vulcan, for it was his observation of the object, on March 26, 1859, which led Le Verrier to work out its orbit and assume its existence The credit, however, merited by Lescarbault as an observing astronomer, can be estimated when it is stated that he announced to the Academy of Sciences that, on the night of January 11, 1891, he discovered a bright body in Leo, which he concluded to be a new star or one suddenly increased in brilliancy The "new star," however, proved to be the ancient planet Saturn!

Mercury—The discovery of Mercury dates so far back into antiquity that no record has been handed down as to the name or country of the individual who effected it Great credit is attached to the feat, for it needed acute vision, a comprehensive knowledge of the stars, and a discerning mind It seems very probable that, when the planet was first observed alternately in the morning and evening twilight, it was supposed that two different objects were involved The similarity of aspect and regularity of the apparitions must soon however have afforded unmistakable evidence that one and the same body was concerned in producing them What a thrill of pleasure the first observer must have experienced, after all his watchings, in realising the novelty and importance of his discovery! And how intensely interested others must have been in corroborating it as the sparkling little planet shone out morning after morning or evening after evening and unfolded to willing eyes the true story of its existence Possibly one of the Chaldean shepherds was the happy discoverer, but the world has no historical account of it and, though we can applaud the feat accomplished, we cannot honour the name of the individual

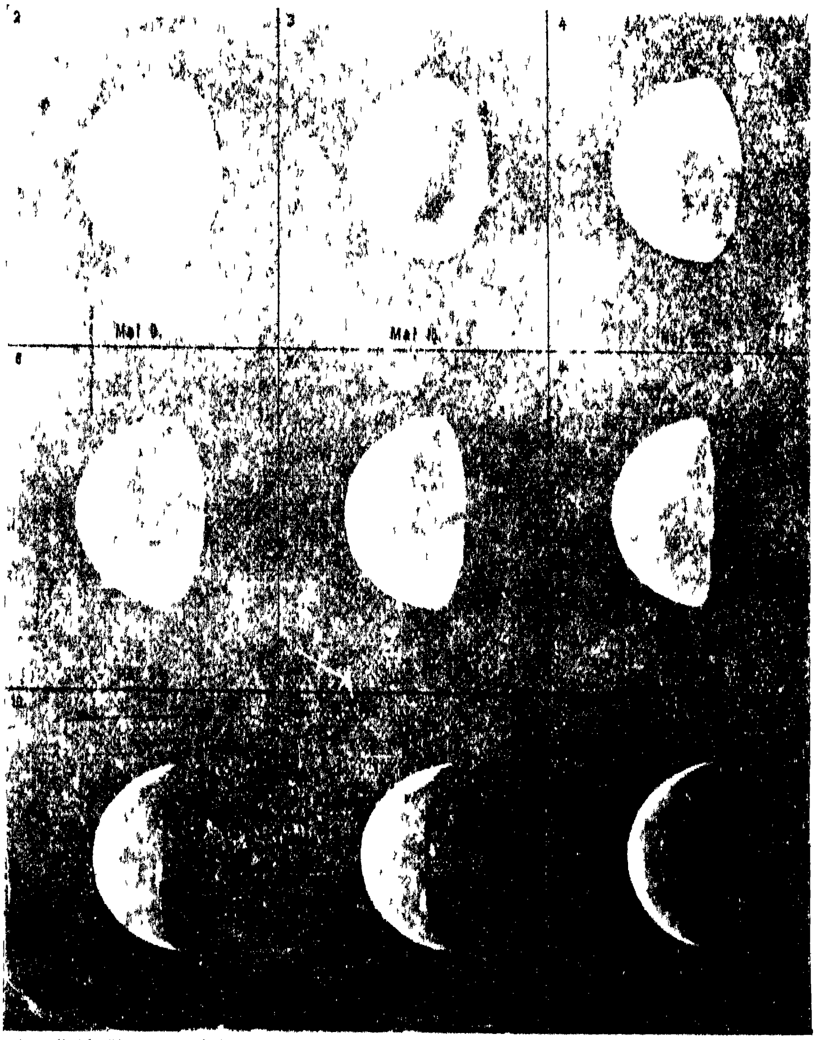
Observations of Mercury date back to the year 265 before the Christian era, but there is an earlier

record in which the chief astronomer at Nineveh mentions the planet in a report he made to the King of Assyria

The celerity of movement of this planet caused him to be known to the ancients as "The swift-winged messenger of the gods" This was not the only appellation given to Mercury, for his fitful lustre, when visible to the naked eye, amidst the dense and often disturbed atmosphere near the horizon, led the Greeks to call him "The strongly sparkling one"

This is the nearest known planet to the Sun, his mean distance from that orb being 35,958,000 miles, sidereal period of revolution eighty-eight days, and real diameter 3,008 miles

Mercury can only be observed by the naked eye about the time when he reaches his greatest apparent elongation from the Sun, west or east, and this never exceeds twenty-eight and a quarter degrees At such times the planet either rises or sets about two hours before or after the Sun In the spring months of the year the elongations are favourable for viewing him as an evening star, and in autumnal mornings he may be equally well discerned as a morning star At such times, since his declination is north of the Sun, he remains above the horizon in the absence of that luminary for longer periods than at other times, when his declination is south He sometimes appears to be brighter than a star of the first magnitude, and is really a conspicuous object to the naked eye His position, however, being near the horizon and involved in twilight, he shines with a sparkling, ruddy lustre, scintillating in somewhat similar fashion to that of the stars



From "The Heavens and their Story," by A and W Maunder [*By permission of the Epworth Press*

CLOUD-LIKE MARKINGS ON VENUS

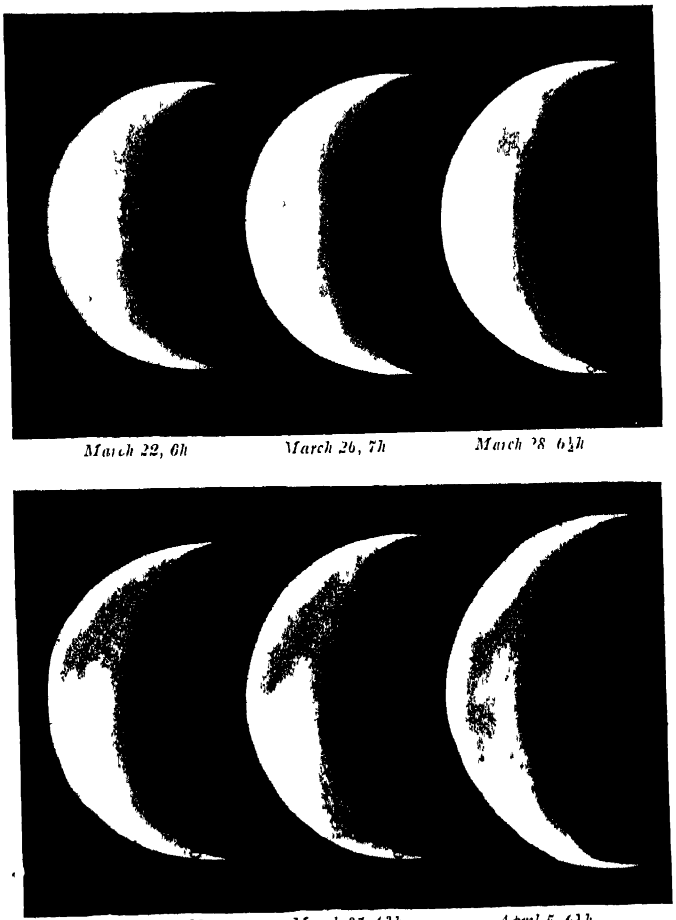
Large bright patches, similar to those depicted above, are very often observed on Venus They have been attributed, with considerable probability, to masses of cloud floating in the planet's atmosphere Variations in their shape, size and position seem to confirm this explanation The remainder of the surface of Venus is only a little less bright than the white patches, but, to bring out the latter, it is necessary on a drawing to exaggerate its duskiness These drawings were made at the Bothkamp Observatory

In the English climate, Mercury may be seen with the unaided eye on about fifteen occasions annually, but much depends upon the atmospheric conditions prevailing at those special periods when the planet occupies the best position for observation

It has been said of Copernicus, who was the greatest astronomer of the

Sixteenth Century, that he never caught a glimpse of Mercury though he had frequently endeavoured to do so. The suggestion has been made that a probable cause of the failure existed in the fogs which arose from the river Vistula, running near Thorn, where Copernicus resided. The whole incident, however, has been regarded as a mere legend, or in any case to have resulted from misconception of the writings of Copernicus.

One of the first observational feats attempted by astronomical beginners is to catch a glimpse of Mercury. His position and times of rising and setting can be found from an almanac, and if the would-be observer looks in the right direction at the correct time, and with a clear atmosphere near the horizon, the fitful lustre of the little planet will probably be soon detected. The picture will afford the beholder a peculiar satisfaction and prove an incentive to attain further successes.



March 22, 6h *March 26, 7h* *March 28, 6½h*

March 30, 6¾h *March 31, 6¾h* *April 5, 6¾h*

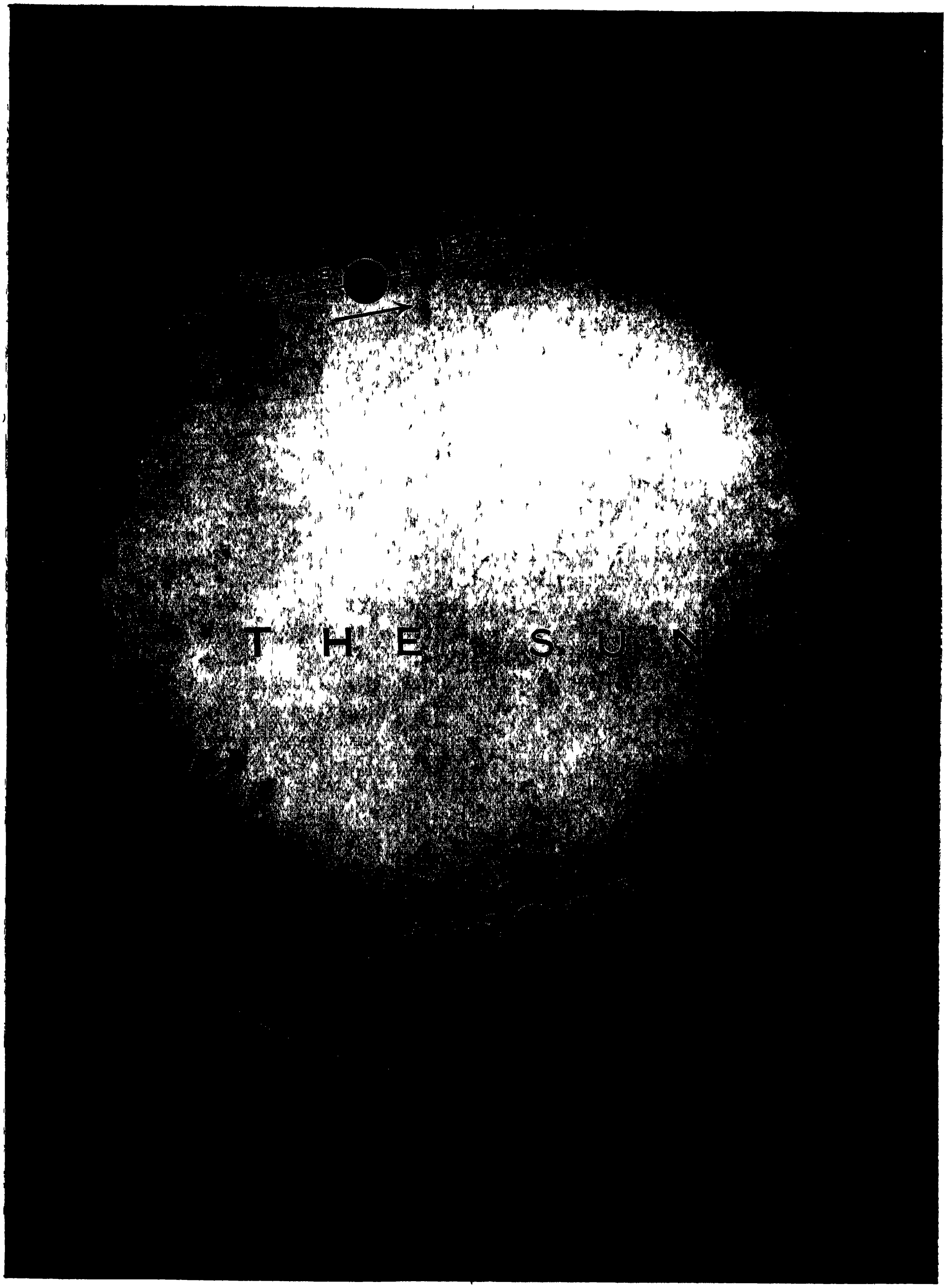
Drawing by] [*W. F. Denning*

VENUS, 1881

More often than not, Venus appears almost completely devoid of markings. Occasionally, however, faint dusky patches and bright areas are seen, and these can sometimes be identified with fair certainty (as in the drawings above) night after night. They appear, however, to be of a temporary nature, and are not surely recognisable after long periods.

This planet is considered by many observers to be involved in a dense atmosphere, which obscures his actual surface markings and shelters his landscape from the intense heat of the Sun. Telescopic power reveals certain features on the apparent disc, but they consist of faint, irregularly shaped, dusky spots and white areas, which are probably existent in the outer limits of his atmosphere, and have no durable characters. At any rate observers have not been able to chart the features on the disc with the same certainty and accuracy in regard to the chief details, as they have attained in regard to Mars. In fact the visible aspect of Mercury appears to be of a different nature and to represent, similarly to that of Venus, the phenomena of an active vaporous envelope.

The position of Mercury near the Sun is very unfavourable for the telescopic study of the planet's markings. He is seldom to be examined to advantage, and especially with magnifiers sufficiently high for the purposes required, for with every increase of power definition suffers owing to atmospheric disturbances and telescopic imperfections. The rotation period of Mercury is not known with certainty but it is probably about twenty-five hours. Observations by Schroter, in about 1800, indicated the period as twenty-four hours four minutes. Other observers have approximately corroborated this value. Schiaparelli however concluded, from his study of the planet in the years 1882 to 1889, that the rotation was performed in the same period as the planet revolved around the Sun, viz., eighty-seven days twenty-three hours. This meant that the planet always turned the same hemisphere towards the Sun,

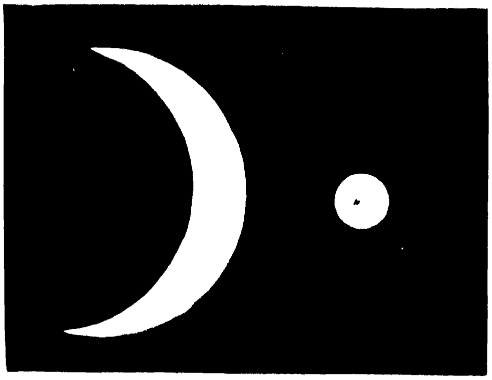


TRANSITS OF VENUS IN THE NINETEENTH CENTURY

Owing to the fact that the path or orbit of Venus round the Sun is considerably tilted with regard to the plane of the Earth's revolution, it seldom happens that Venus passes directly between us and the Sun. Generally she passes well above or below the latter. Transits, when they do take place, occur in pairs, with eight years between each transit. There is then an interval of either 105½ or 121½ years. Thus only two transits occurred in the Nineteenth Century, in 1874 and 1882, and the next pair are due respectively in 2004 and 2012. At each transit, as shown in the illustration, Venus passes across a different portion of the Sun's disc.

similarly as the Moon does to the Earth The whole matter of the planet's rotation, however, is doubtful

Mercury requires further careful observation at periods when he is sufficiently distant from the Sun to be satisfactorily viewed It will be an important object accomplished when the rotation period of both Mercury and Venus are found on evidence beyond disputation

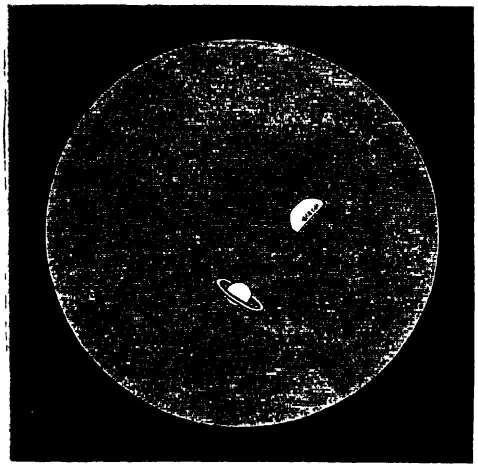


APPEARANCE OF VENUS WHEN NEAR AND FAR AWAY

Venus, when nearest the Earth, turns chiefly her dark side towards us, appearing as a thin crescent When at her farthest, she shows us the whole of her illuminated face, but her apparent diameter is greatly reduced

Mercury being a little planet, and even less in magnitude than the third satellite of Jupiter, presents a small disc for scrutiny, apparently varying, according to distance, between five and thirteen seconds of arc When nearest to the Earth (at inferior conjunction) he is invisible, his illuminated surface being turned away from us, but when farthest from the Earth (at superior conjunction) he presents a circular, though very small, disc In the course of a revolution he presents to us all the phases of the Moon, and these are observable with the help of a telescope In fact, the phases of the planet, especially when crescented, form the most attractive aspect under which he can appear Mercury was called after a celebrated god of antiquity, whom the Greeks termed Hermes He was said not only to be the messenger of the gods, but also the patron of travellers He is usually represented with a wing, cap and sandals, and as carrying a wand around which two serpents are entwined He was armed with a short sword

Without an atmosphere Mercury would be scarcely habitable owing to the intense heat of the Sun, for it must exceed that received by the Earth in the proportion of seven to one If life however is maintained on the planet it would be specially adapted to the conditions prevailing there



CONJUNCTION OF VENUS AND SATURN, 1845, DEC 19

On rare occasions two planets are seen so nearly in the same direction in the Heavens (though at very different distances) as to be visible in the same telescopic field On such occasions the colour, shape, size and brightness of the two are very readily compared When Venus is one of the pair, she is always seen to be incomparably the brighter and whiter of the two

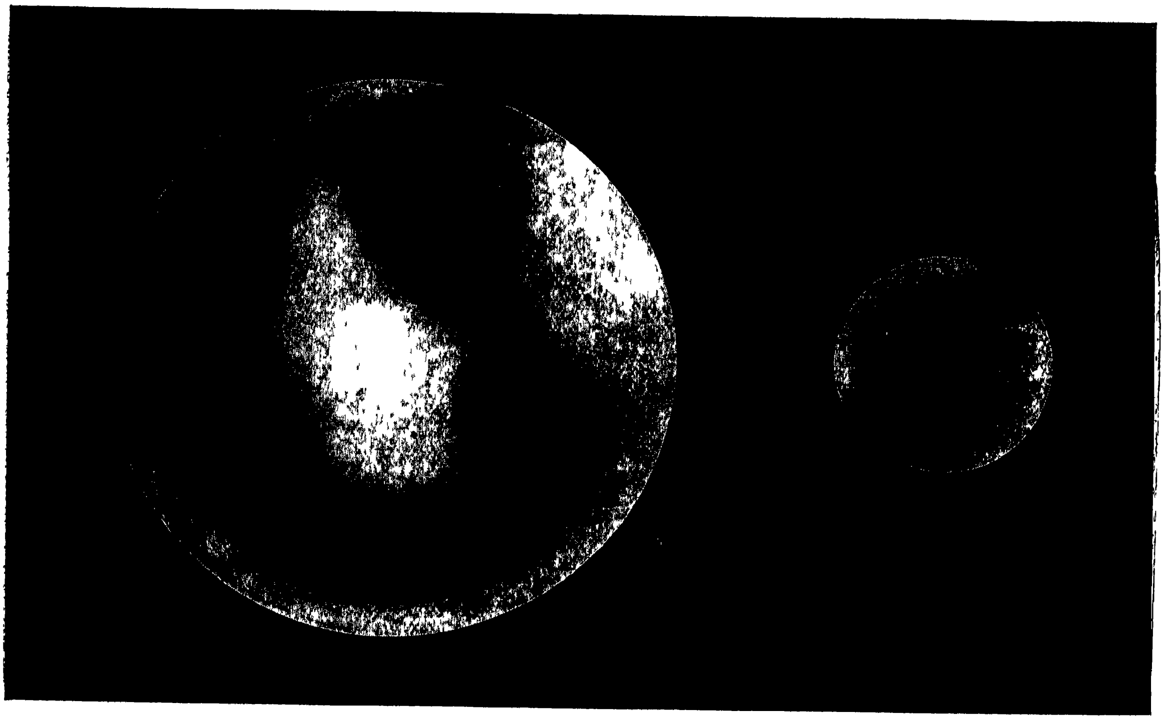
Transits of the planet across the disc of the Sun occur on an average once in six years, and they afford interesting opportunities for the telescopic observer They take place at inferior conjunction with the Sun when the planet passes directly between the Sun and Earth from east to west They do not happen at every conjunction because the inclinations of the orbits of Mercury and the Earth are such as to allow Mercury to pass a little above or below the solar disc The positions of the planet are sometimes favourable in May and November for the occurrence of transits, and they never take place in any other months of the year The following are the dates of the transits which will occur during the present century —

1924	May 7	1960	Nov 6
1927	Nov 8	1970	May 9
1937	May 10	1973	Nov 9
1940	Nov 12	1986	Nov 12
1953	Nov 13	1999	Nov 24

During transit Mercury is observable as a small, round, black spot on the Sun, and some curious details have been noted A small, white spot has been seen on the planet and a luminous aureole has apparently surrounded

it The spot has, however, been disputed, and there is a singular want of harmony in the observational testimony The aureole, the reality of which is also doubtful, has been explained on the assumption that the planet has a perceptible atmosphere The central spot is probably a mere optical effect

The conditions regulating the visible displays of Mercury as a morning and evening star are repeated every thirteen years (after fifty-four revolutions) at nearly the same times as before Thus the evening elongation on May 5, 1923, will have a repetition a few days later in May, 1936 Mercury, being situated so near to the Sun, ought to appear much brighter than he does if his atmosphere possessed the same capacity for reflection as that of certain other planets The albedo, or reflective power, of Mercury is rated at only seventeen, while the value for Venus and Jupiter is about sixty-five, and that of clouds seventy-two Apart from the changing phases of the planet, the state of our atmosphere and the intensity of the twilight involving his position, bring about material variations in his apparent lustre In a February or March sky he usually appears much brighter than in the



THE EARTH AND MERCURY COMPARED

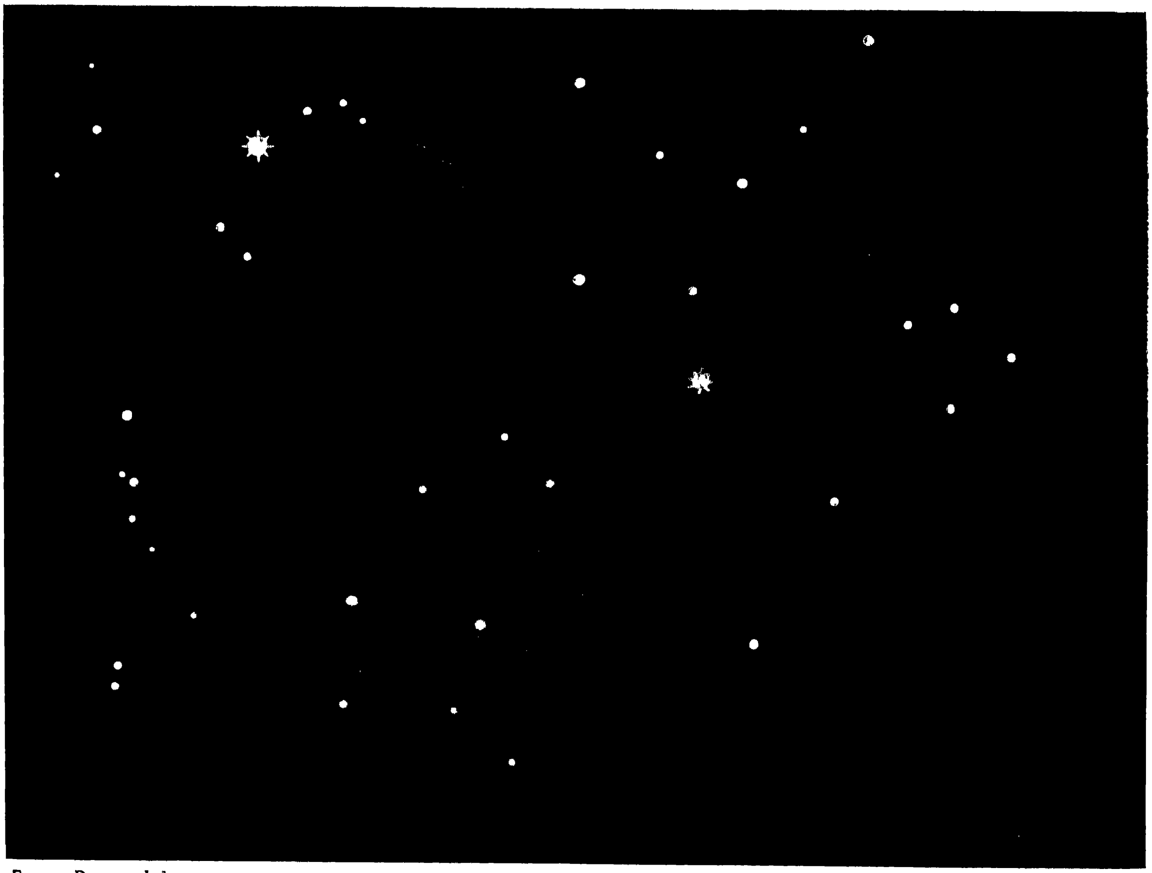
Mercury is considerably less than half the diameter of the Earth He is quite the smallest of the major planets and is about the size of the largest satellites of Jupiter and Saturn Gravity at the surface of Mercury is about a quarter of what it is on Earth, so that a terrestrial pound of sugar would weigh only four ounces on the smaller planet

strong twilight of May or June At the best times he has shone with nearly equivalent lustre to Jupiter, but the far greater steadiness of the rays from the Jovian orb is always very marked Under normal conditions he becomes within reach of a good eye about half an hour after sunset, and shines most strongly (when the western quarter is clear right down to the horizon) about the same interval before he sets

There are times, however, when a rapidly narrowing crescented phase may so enfeeble his light that he may be detected with difficulty, though he remains above the horizon some two hours after the Sun

Mercury has never been studied sufficiently under telescopic power and at times best suitable for the detection of his surface markings There is here a very valuable piece of observational work

awaiting some capable student It is chiefly amateurs who investigate the physical aspect of the planets, and they should specially direct their attention to Mercury and the determination of his rotation period This important element might be found for all time if a spot could be seen, clearly and definitely, on the planet's disc, its position recorded and a few subsequent views obtained of the same object If it remained stationary, then the long period alleged by Schiaparelli and other observers would be proved, but a rapid motion of the spot would uphold the shorter time, and show that not only Mercury, but Venus also by inference, rotated in periods not essentially differing from those of the outer planets A marking which would aid the solution of the problem might present itself at any time Saturn, after many years of apparently tolerable quiescence, exhibited, in June **1903**,



From a Drawing by] [*W F Denning*

THE MORNING ZODIACAL LIGHT

The observation here illustrated was made before dawn at Bristol on December 3, 1916 The Light was noted as being unusually bright, though the atmospheric conditions were far from perfect This would tend to support the theory that real changes of brilliancy occur in the Zodiacal Light More often such apparent changes are directly attributable to alterations in the transparency of our skies

a very disturbed condition of surface, and large white and dark spots appeared in the northern hemisphere These soon indicated a rotation period about twenty-three minutes longer than the previous determinations of Herschel (1793) and Hall (1876–7) Similarly the atmosphere of Mercury may become sufficiently active to present the necessary features and the disc should be carefully watched when the planet is high in the daytime, for low altitude means bad definition

Mercury may not be, in himself, one of the more splendid objects in nature, but he often forms one of the chief brilliants in real sky pictures of charming character When occasionally visible in

the twilight glow, the crescent of the Moon and possibly Venus or another planet may be near, and compose an interesting and striking group for contemplation

Venus—This planet was appropriately known to the ancients as the "Goddess of Beauty," and never was a title more justly merited, for Venus has a silvery splendour all her own and without a parallel among the other planetary orbs of the Solar System Jupiter may shine with his strong, pale-yellow light, and Mars, when favourably placed, may emit a brilliant, fiery-red lustre, but neither of these objects can compare with the refulgent beauties of Venus She forms a resplendent picture either in the morning's dawn, heralding the Sun in his rising glory, or in the evening's twilight, lingering over the glow where he has just set amid gilded clouds

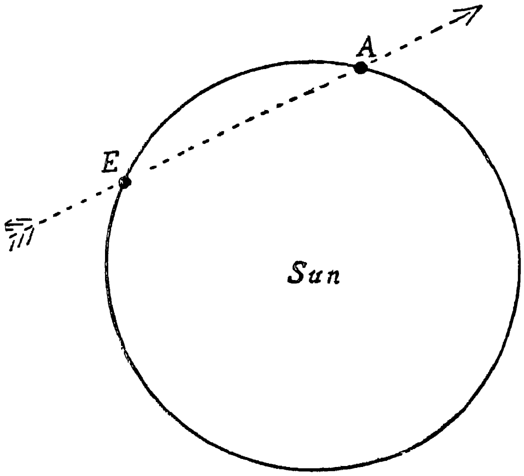
From a Drawing by] [*W F Denning*

THE EVENING ZODIACAL LIGHT

The Zodiacal Light is here shown as observed in Bristol in the month of March It is in the early spring that the best views of the Evening Light are secured, since the Sun's path, or ecliptic (in which the Light appears) is then well raised above the mists and smoke of the horizon For a similar reason the Morning Light is best seen in autumn

There is perhaps no more beautiful scene than a sunset with Venus "the evening star," and gorgeous cloud scenery enveloping all the western sky At such times the pageant of Nature forms a deeply attractive and impressive spectacle. Sometimes the crescent of the young Moon adds a charming effect, and we may contemplate the deepening hues and changing tints until the dusky shades of night silently draw their veil and display a myriad starry brilliants in the blue heavens

Among the more entertaining observations suitable to the unaided eye the monthly conjunctions of Venus with the Moon and her occasional approaches to other planets may be regarded as taking a foremost place These occurrences are given in *Whitaker's Almanack* and other annual publications



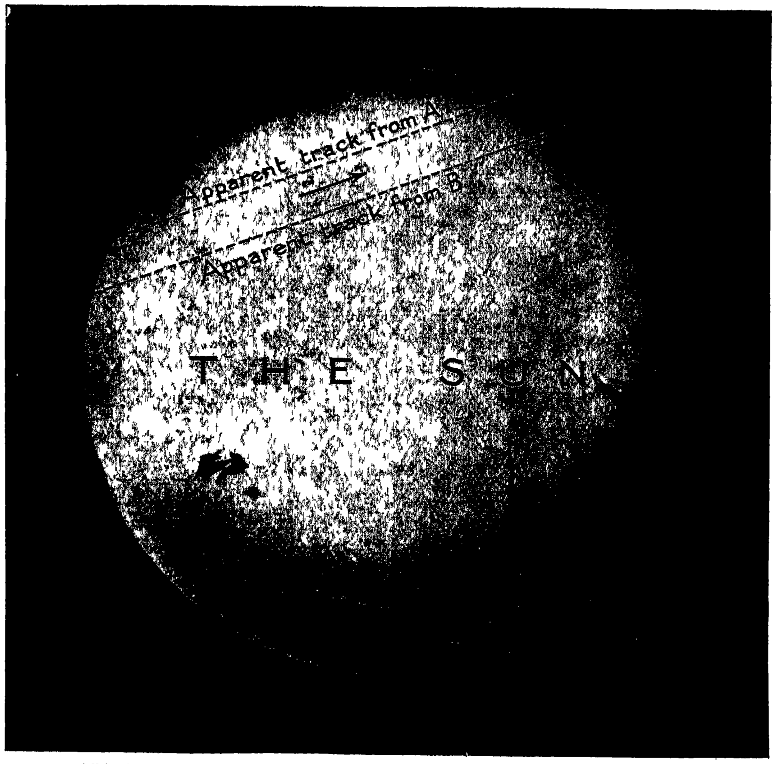
TRANSITS OF MERCURY
Mercury passes between the Earth and the Sun much more frequently than does Venus Transits occur, on the average, about every six years They always take place either in May or November

of similar character, so that an intending observer will always find the date and time given, and may easily witness such of these events as occur in clear weather

This planet is frequently visible in the daytime when the atmosphere is suitable and the sky is of a deep blue colour A person of ordinary sight and knowing the position of the planet can often see her without difficulty with the unaided vision even at noonday Venus has often been mistaken for a new and brilliant star, or for some special celestial object, by persons not well acquainted with Astronomy Her astonishing brilliancy misled many people during the trying period of the Great War to suspect that she was suspended in the sky as a signal, and many anxious enquiries were made as to her identity

Venus is situated at a mean distance from the Sun of 67,200,000 miles, her real diameter is 7,480 miles, and sidereal period of revolution (i e, relatively to the stars) 224 7 days Her apparent diameter varies between eleven and sixty-seven seconds of arc When near inferior conjunction (i e, in a part of her orbit between the Earth and the Sun), and comparatively near the Earth, she is in the form of a narrow crescent and presents an attractive aspect, looking as she does like a bright, silvery bow in the blue sky This effect is, however, only to be seen in a telescope, though it has been alleged that the crescented outline has been detected with the naked eye, but this needs confirmation

The elongations or apparent distances of Venus from the Sun vary to a small extent, and usually amount to about forty-five or forty-seven degrees When the eastern elongations occur in the spring months and the planet is very favourably visible as an evening star, her position being north of the Sun's place, she sets about four and a half hours after the Sun Similarly her morning (western)



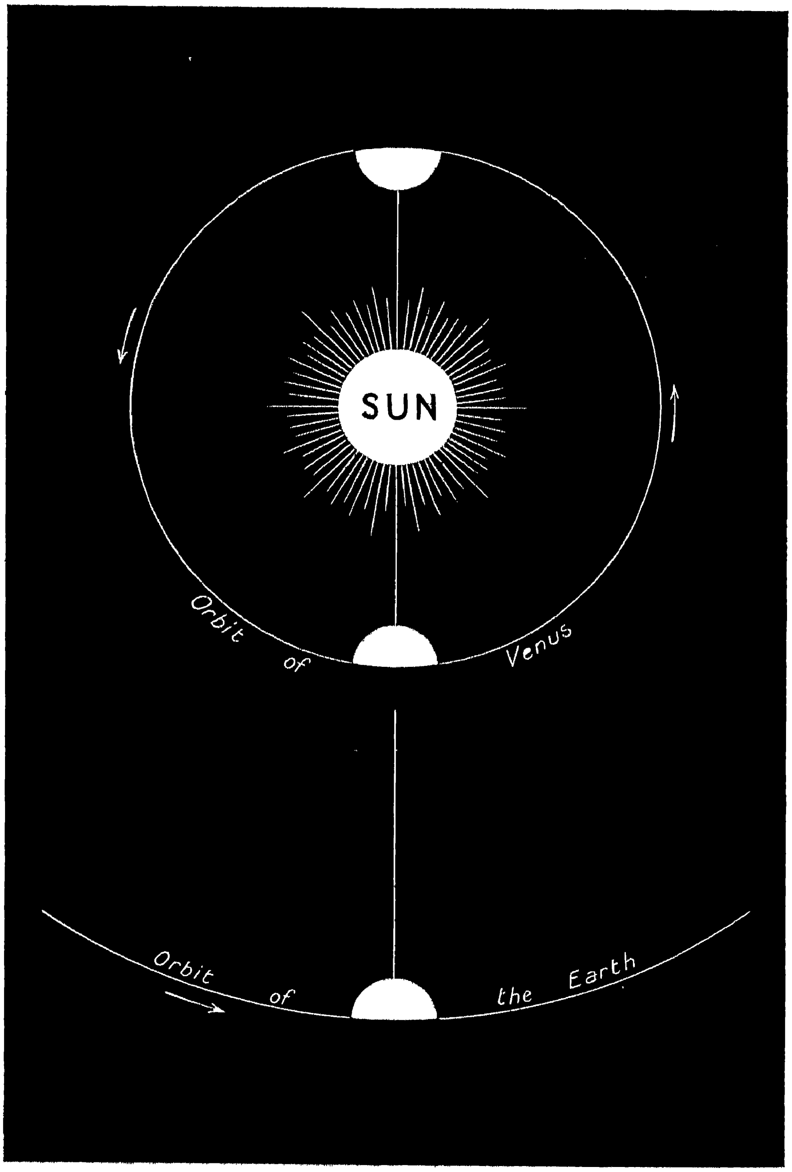
HALLEY'S METHOD OF FINDING THE SUN'S DISTANCE
If a transit of Venus is observed simultaneously from two points, A and B, on the Earth, the planet will appear to follow slightly different paths across the Sun's disc The two places have to be chosen as far apart in a north-south direction as possible, and from the apparent distance between the observed paths and the known distance between the two places we can calculate the size of the Earth's orbit

elongations, during the latter half of the year, are very favourable for observations either with the naked eye or telescope. Her maximum brightness is attained at a period of thirty-six days either before or after inferior conjunction, when her disc is about one-fourth illuminated and the diameter of the crescent about forty seconds of arc. At intervals of eight years (thirteen revolutions) the conditions favouring the visibility of Venus return at nearly the same dates as before. The difference is one amounting to only two days, as the following comparison will show:—

Year	*Eastern Elongation*	*Western Elongation*
1900	April 28	September 17
1908	April 26	September 14
1916	April 24	September 12
1924	April 22	September 10

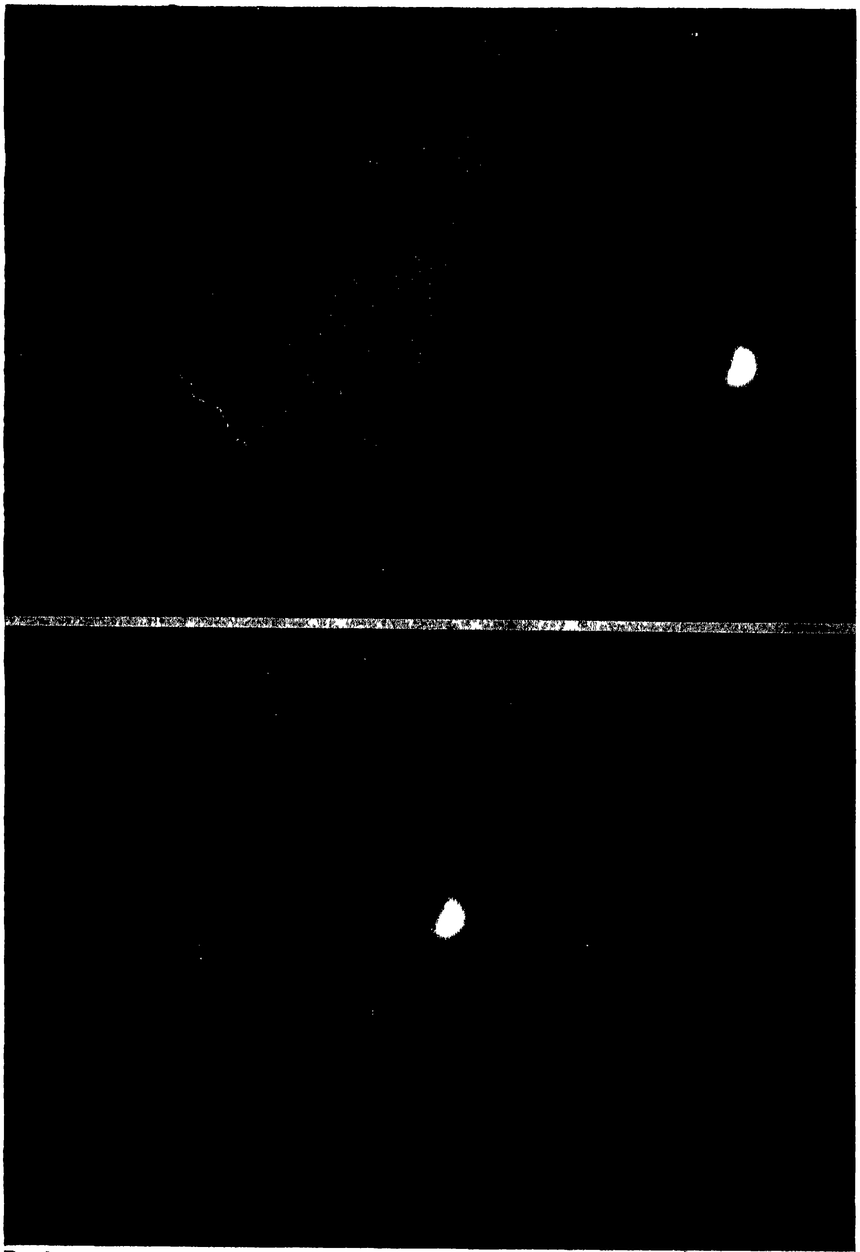
The planet will repeat her brilliantly favourable apparitions in 1932, 1940, 1948, 1956, and in years subsequent to those mentioned consistently with the cycle of eight years. In some seasons Venus is practically missing, and fails to ornament our sky. However, even during unfavourable years she may be occasionally glimpsed near the horizon, but on such occasions her position is so involved in the strong twilight that her lustre appears much moderated, and she is not the same brilliant, queenly orb as when she shines under the best conditions.

As a telescopic object it must be confessed that Venus is disappointing. Her lustrous aspect encourages an expectation which is far from being realised. The white disc, free from obvious detail, such as that which diversifies Mars and Jupiter, does not call for interested study, though, if the planet be crescented, the picture is a very attractive one and gratifies the eye. The student however is apt to tire of a similarity of aspect. It is the study of detail and of changes in the forms and motions of features which so pleasantly maintains the interest in planetary work and furnishes results which



VENUS AND THE EARTH

This diagram (which is not to scale) shows roughly how the orbits of Venus and the Earth are situated with regard to one another. Strictly speaking, Venus should be nearly three quarters of the way from the Sun to the Earth. The two planets, Venus and Mercury, both have orbits that lie within that of the Earth, and they are known as "inferior" (that is, interior) planets



From] [" *L'Astronomie* "

VENUS OCCULTED BY THE MOON, 1921, JULY 2

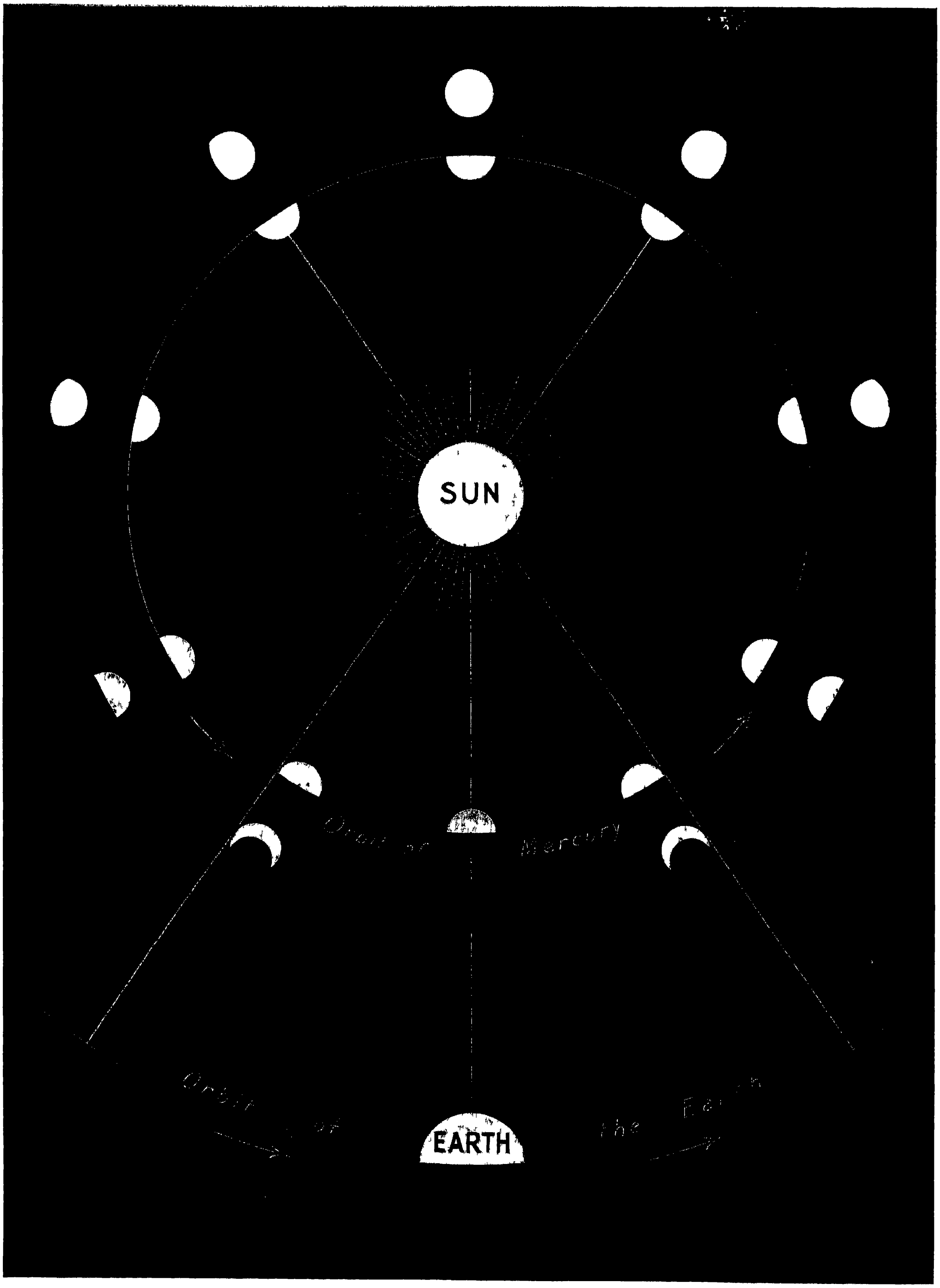
The hiding of one celestial body by another is known technically as an " occultation " In this picture we have photographs illustrating two stages in the occultation of Venus by the Moon, 1921, July 2 The Moon is to the left of each photograph, and the scale is so large that only a portion of the whole crescent is included Venus was about half-illuminated at the time, and appeared intrinsically very much brighter than the Moon, as is shown on the photographs This picture is upside down as compared with the small drawing showing both objects in the morning sky

are important In this respect Venus may not apparently take a leading place, although the keen observer may always find something to allure investigation Schroter's mountains may not present themselves, but there will probably be the dusky areas, brightness of the horns and margin of the disc, and, possibly, slight unevenness along the curve of the terminator or line of sunrise or sunset on the planet's surface Indentations are sometimes noticed as though depressions actually existed, either atmospheric or otherwise

Some of the markings seen or imagined to exist on Venus have certainly been illusions, others have received the corroboration necessary to remove every possible doubt as to their objective reality. One instance of a reliable observation was made on February 13, 1913, by McEwen of Glasgow and Sargent of Bristol, who simultaneously detected a very obvious and rather deep indentation in the terminator of the planet Faint, cloudy and indefinite markings have certainly been sometimes traced on the planet's disc, and they appear to be slight inequalities of tone in the atmosphere rather than real features on the surface They apparently cover extensive areas and have eluded the scrutiny of some of the best observers Schroter saw them at the end of the Nineteenth Century, but his great contemporary, William Herschel, failed to perceive anything, and expressed himself

THE TRANSIT OF VENUS

The transit of Venus across the Sun's disc, which took place in 1874, was the first that had occurred for over a century. Excitement over the event was not confined to scientific circles, but appears to have extended to many not ordinarily concerned with the phenomena of Astronomy. The picture reproduced above (showing the goddess Venus about to pass in front of the chariot of the Sun-god, Phœbus), represents an attempt by a French artist to give an allegorical interpretation to the event.

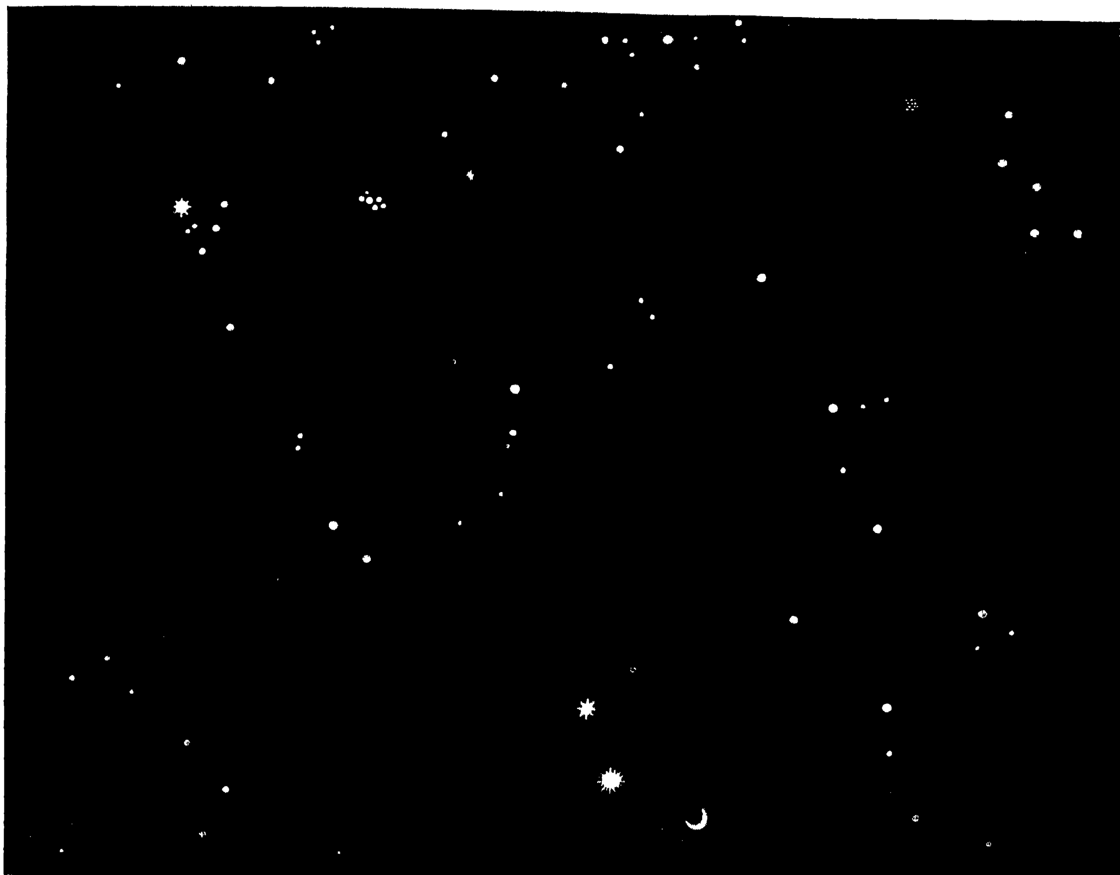


EXPLANATION OF THE PHASES OF MERCURY

Mercury, like the Earth and all the other planets, has a bright and a dark side, since it depends entirely on the Sun for its light. An observer on the Sun would see only the illuminated side, so that the planet would always appear "full." On the other hand, an observer situated outside the orbit of Mercury (as we on the Earth) would see at different times very different proportions of the bright side, and sometimes even none at all. On the diagram, the inner circle shows the true state of affairs, while just outside are the corresponding appearances of Mercury as seen from the Earth.

strongly as to their non-existence Dawes and others, in more modern times, supported the negative view of Herschel, but on the other side so many observers have glimpsed the dusky areas that they cannot be rejected as illusions due to imagination

The feebly outlined markings often seen on Venus certainly do not require a large telescope to show them Though this is a small planet of about the same dimensions as the Earth, her apparent size is large as she approaches near to us, and sometimes equals one minute of arc With moderate magnifying power, therefore, her disc is fairly expansive, and any conspicuous features presented on it ought to be easily recognised It is perhaps a curious fact that some observers looking at Venus



From a Drawing by] [*W H Steavenson*

THE ZODIACAL BAND, 1916, FEBRUARY 5

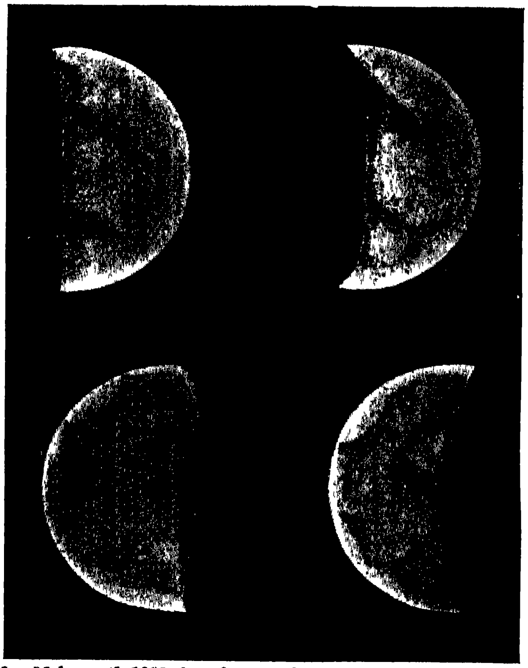
Under good conditions a faint narrow extension of the Zodiacal Light can be traced for some distance beyond the "apex" of the bright cone of the Light It has, on occasion, been traced completely round the Heavens to its junction with the apex of the "morning" cone This faint extension is generally known as the Zodiacal Band It is seldom observed in this country

with three- or four-inch telescopes have remarked spots, whereas observers with much larger, and presumably more effective instruments, have quite failed to perceive them An explanation may partly lie in the fact that a large glass produces such a brilliant image that feeble details like the faint, dusky areas on Venus are practically obliterated in the glare More than one student of planetary markings have tried the experiment of comparing a fairly large and small telescope side by side on the markings of Venus, and the result has been that in the smaller instrument the features have appeared to be more obvious than in the larger one

It has been argued that this result really proves that small telescopes have insufficient grasp to deal effectively and reliably with planetary markings, and that the comparatively faint images are

liable to produce false impressions This however is not at all certain, and the problem remains unsolved, though we may naturally expect more reliable work with large apertures As bearing on the point an observation and drawing of Venus made on May 29, 1889, may be mentioned The well-known observer, Barnard, wrote that dark markings seem undoubtedly to exist on the planet, and that he never afterwards had such perfect conditions to observe Venus, adding that a twelve-inch equatorial at the Lick Observatory was found to be superior to the thirty-six inch for viewing this difficult object

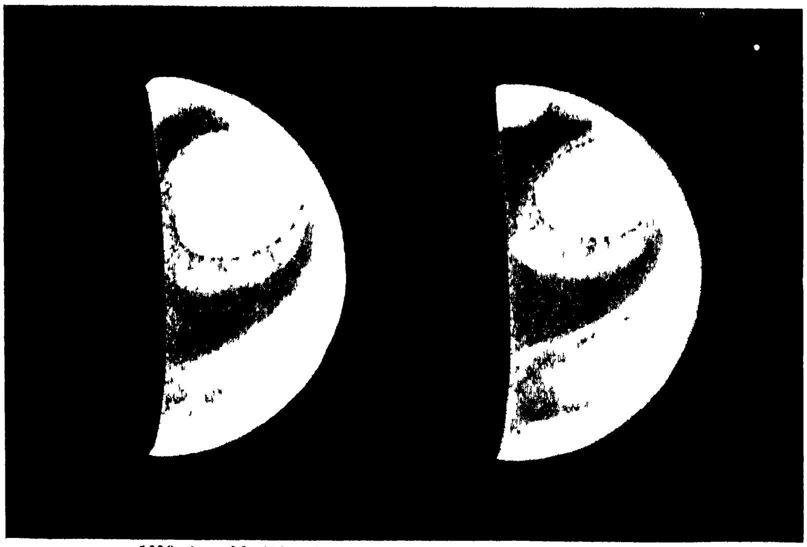
Schroter, in 1789, found the rotation period of the planet to be 23 hours 21 minutes 7 98 seconds from the dusky spots, and J D Cassini had arrived at a nearly similar period forty years before, viz , 23 hours 20 minutes 55 seconds Later observers have approximately corroborated the results mentioned, but Schiaparelli concluded that Venus, like Mercury, rotates in the same period as she revolves round the Sun, viz , 224 days 16 hours 49 minutes The latter period was arrived at after an elaborate discussion of existing data, and after a telescopic study of the planet by the author of it, and it appears to have received corroboration from a few other astronomers There is however a large amount of evidence opposed to it, and it must be confessed that the actual rotation period of Venus, like that of Mercury, is one of the unsolved problems of Astronomy



1 Molesworth 1898 June 2 2 Brenner 1896, May 9
3 Molesworth 1898, April 2 4 Molesworth 1898, April 8

SOME VIEWS OF MERCURY

Owing to his low altitude near sunset or sunrise, Mercury is not so well seen then as in the full daylight when he is high in the sky A good telescope will then reveal faint dusky markings that are not always easy of identification over long intervals Moreover, observers differ greatly in their portrayal of the markings and we still lack a reliable map of the planet's surface



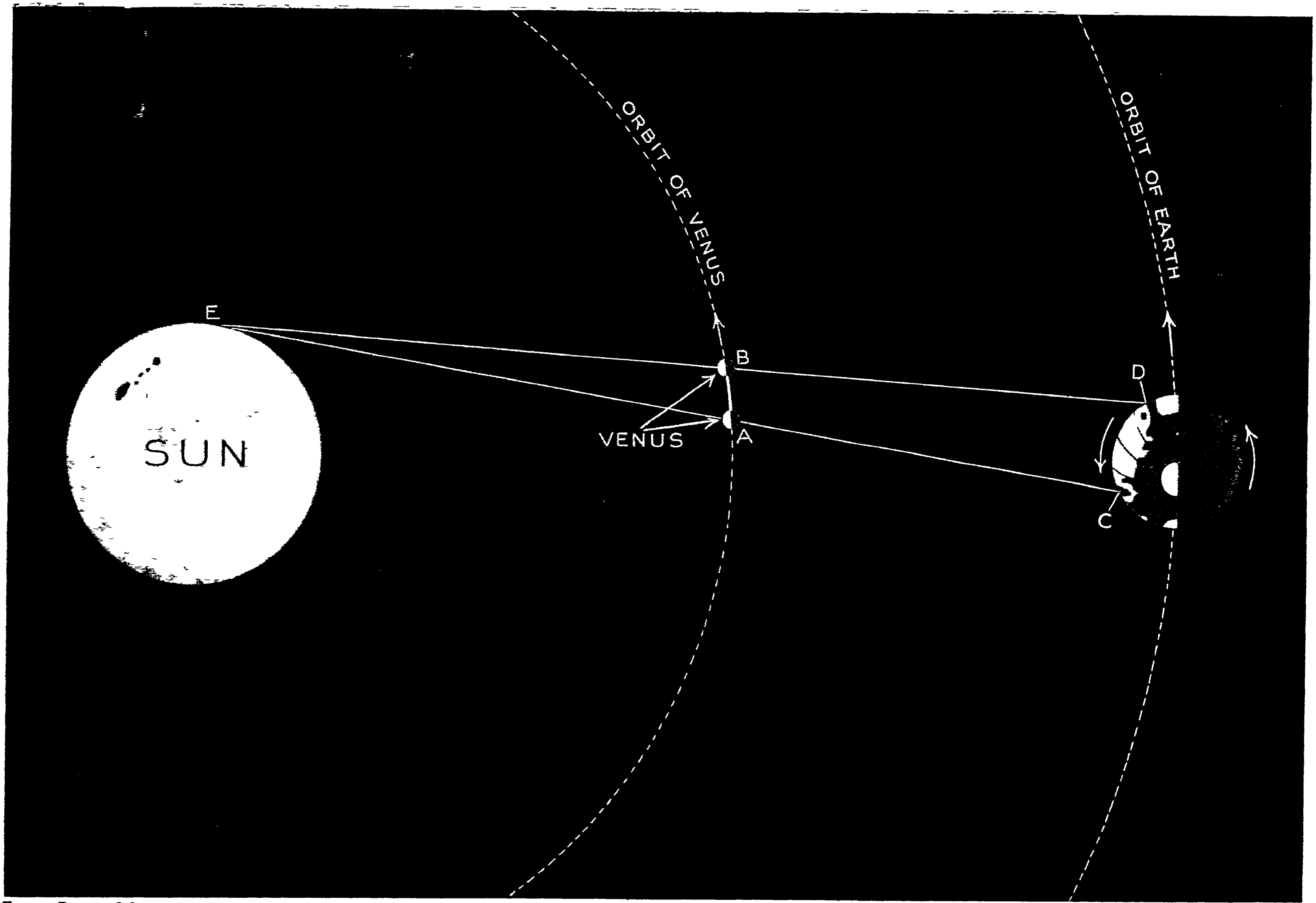
Drawing by] 1906, Aug 30, 17h 45m Sept 1, 18h 10m [W F Denning

MARKINGS ON MERCURY

This is an instance in which the same markings on Mercury were identified with reasonable certainty on two separate occasions Their movement on the disc appeared inconsistent with a very long period of rotation As often observed, one cusp of the crescent appeared more blunt than the other

Sir John Herschel considered Venus a difficult object and a critical test of definition He remarked that the intense lustre of her illuminated part dazzles the sight and exaggerates every imperfection of the telescope He rightly concluded that we cannot discern the real surface of the planet but only its cloud-laden atmosphere

The first observer to examine Venus and discover her phases was Galileo in



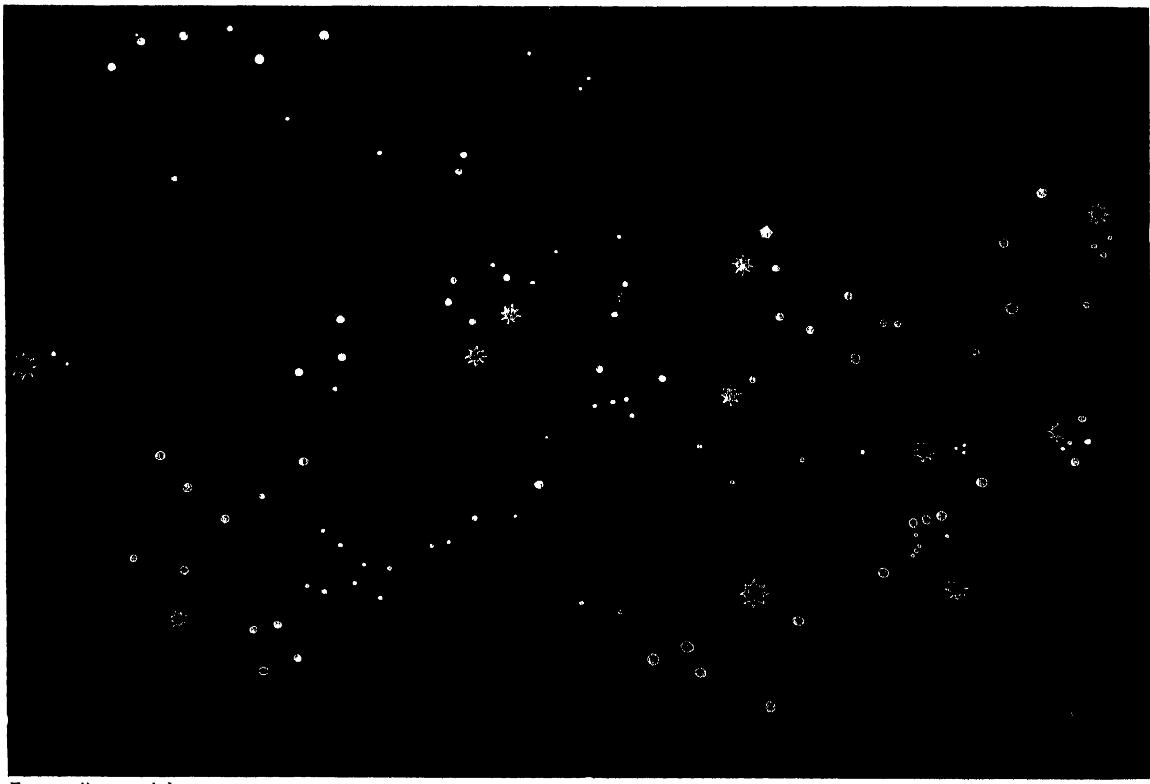
From a Drawing by] [*W H Steavenson*

HOW VENUS GIVES THE DISTANCE OF THE SUN

When Venus passes in "transit" across the face of the Sun she appears to reach the edge of that body at somewhat different times as seen from various parts of the Earth This is due chiefly to her own motion Thus, when at A she appears from C to be at the Sun's edge Later, when at B she is seen similarly placed from D The angle (or proportion of her orbit) traversed by Venus in this interval is known, but, neglecting the Earth's rotation, the line joining D and C clearly makes the same angle at E as does the line AB The *actual distance* C–D being known, the angle subtended at the Sun by the whole Earth is readily deduced Half this value is called the Solar Parallax, and gives us all that we need for measuring the Sun's distance

1610, and in 1643 Fontana detected irregularities along the inner edge of the crescent, while in 1645 he saw a dark spot on the disc Cassini, in 1666, October, saw a bright spot near the inner edge on the northern limb and also two dark spots of extreme faintness He made further observations and watched the markings over sufficiently lengthy intervals to note changes in their position

Flammarion made a pretty exhaustive review of observations of Venus, and published his conclusions in 1897 He found many discordances in the results, in fact the contradictions were of such a nature that no safe and certain conclusions could be derived from them He gave the observers credit for having doubtless done their best, and attributed their want of harmony to "personal equation," and to the difficulties inseparable from the research



From a Drawing by] [*W H Steavenson*

THE COUNTER-GLOW, OBSERVED AT ASHTEAD, 1916, FEBRUARY 5

The faint oval patch of hazy light in the centre of the picture is known as the Counter-Glow, or Gegenschein It is sometimes to be seen on very dark clear nights by observers of sensitive vision It always occupies the portion of the sky exactly opposite to the Sun, and is believed to be intimately connected with the Zodiacal Light It is much fainter than the latter, and is not often observed in England

The spectroscopic method has been tried as a means of determining the rotation period of Venus, but it appears to have given results which are not consistent, and the question is still left an open one

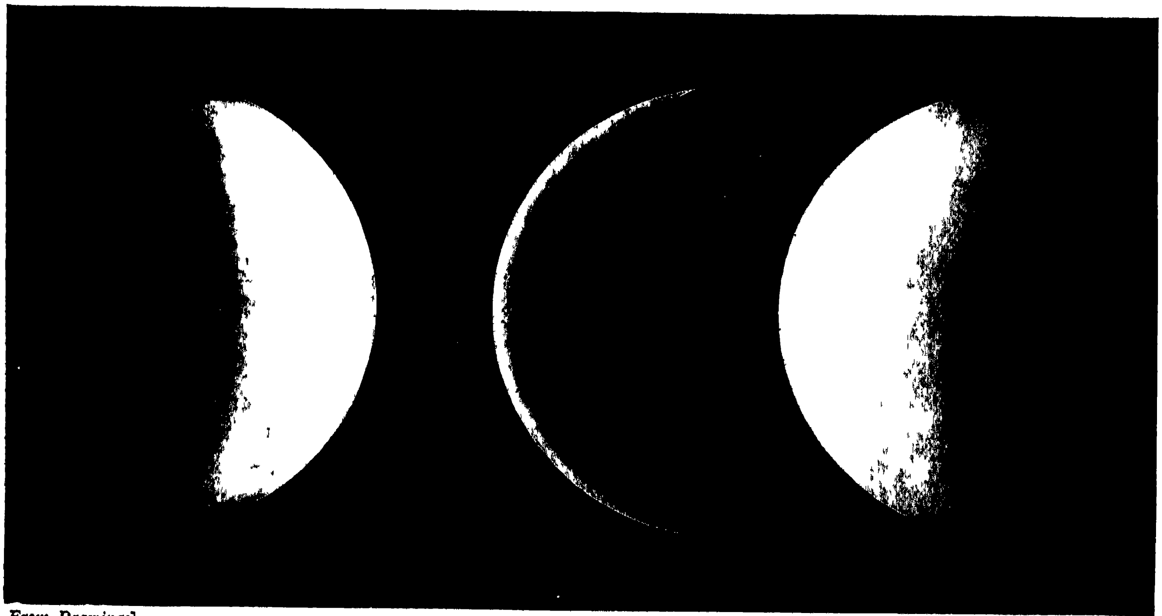
The atmosphere of Venus is probably of great density, and this seems obvious on evidence of a convincing character The planet occulted a star in Gemini, July 1910, and it was noticed by critical observation that at disappearance the light of the star declined during two and a half seconds, and at reappearance its increase occupied one and three-quarter seconds, whereas had the planet possessed a sharply-cut boundary like the Moon the star's lustre would have vanished and returned instantaneously as during a lunar occultation It was computed from the phenomena observed in 1910 that the atmosphere involving Venus must reach an altitude of seventy miles The ring of light sometimes apparent around Venus when in transit across the Sun finds an easy explanation as an atmospheric effect

Mercury and Venus are termed inferior planets, their orbits being nearer to the Sun than the Earth's. They are considered to be the least interesting for telescopic observation, for apart from their phases they present no very conspicuous details or spots of changeable forms and dimensions.

The markings on Mercury, however, appear to be plainer and more definite than those of Venus, and to offer a better prospect to observers for the investigation of the rotation period and physical condition of the planet.

Mars, Jupiter, and Saturn, on the other hand, are known as superior planets, and they individually exhibit highly interesting features for study when viewed under telescopic power. The other superior planets, Uranus and Neptune, form a different class, being situated at enormous distances, and apparently they are of feeble light and small dimensions as viewed from our remote standpoint.

For observing the markings on Venus the best time is in daylight, for the planet shines with almost dazzling splendour on a dark or nearly dark sky, and under such conditions telescopic definition is apt to suffer. In strong twilight, or when the Sun is a little above the horizon, views



From Drawings] [*By Schröter*

DIFFERENT ASPECTS OF MERCURY

These drawings, made by Schroter at the end of the Eighteenth Century, give an excellent general idea of what is seen when a telescope of moderate power is directed towards Mercury. The "cusps" of the crescent, unlike those of Venus, are often heavily shaded, producing an effect of "blunting" at first sight. A similar soft shading is also present along the terminator, which marks the region of sunrise or sunset.

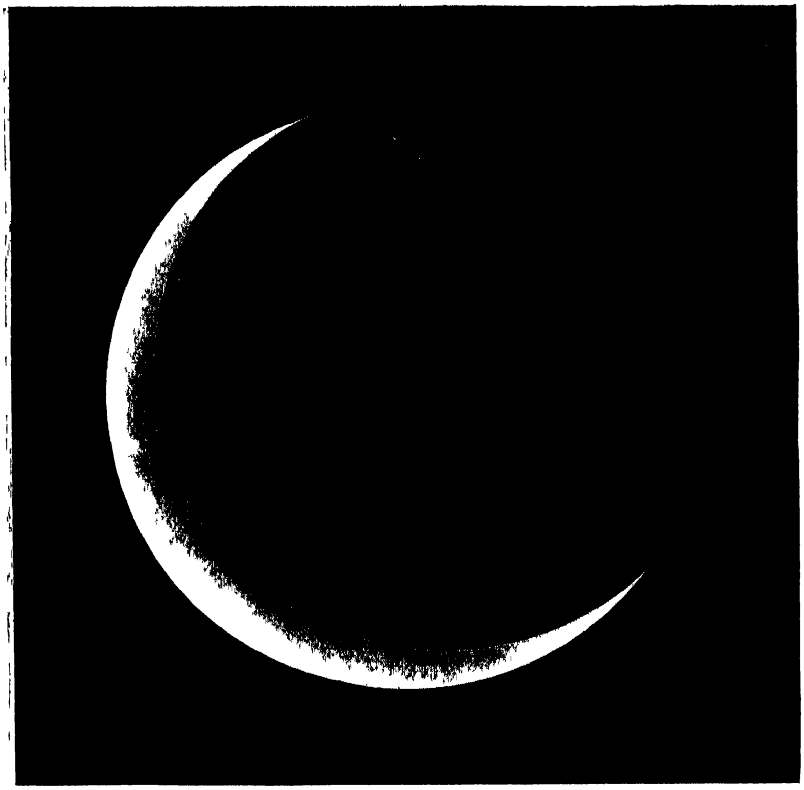
of this planet are frequently very sharp, and delicate features are more easily recognised than at any other period. Her full lustre is apt to exaggerate telescopic defects and to reveal want of achromatism in any but the very best lenses. In the day-time the intensity of the light is toned down in suitable degree. Mercury, too, is often seen to advantage in a light sky and the same may be said of the planets Mars and Jupiter, the details of which come out more keenly and often with livid distinctness about an hour, or half an hour, after sunrise or before sunset. The various planets may be readily found in the day-time, even when the mounting of the telescope is merely an alt-azimuth stand, if the observer knows the approximate place of the object, and uses an eyepiece of low power and large field.

When visible as a morning star, Venus was known to the ancient Greeks as *Phosphorus* or *Lucifer*, and when seen as an evening star was called *Hesperus* or *Vesperus*.

Venus has occasionally displayed the "ashy light" or *Lumière Cendrée*, which is so often remarked

on the dark part of the Moon when she is thinly crescented The fact has been well asserted though not always satisfactorily seen even at such times as all the conditions favoured its presentation The shimmering of the unilluminated part of the disc has been, moreover, corroborated by special observations and is now one of the established details of the planet's features No doubt circumstances affect its visibility, and apparently induce variations in its aspect and tone, but the peculiarity lies beyond disputation and has been recognised by many observers employing different classes and sizes of telescopes under different conditions It is due to changes in the atmosphere of Venus which may not always be equally reflective nor similarly illuminated from exterior sources

The phases of Venus have not always been precisely conformable with calculation, and this is suggestive of marked differences in the height of certain areas There may be extensive hollows and mounds in the outer layer, giving rise to the observed irregularities, such as faint shadings, an uneven terminator and differences in the cusps It might also cause that feebly mottled appearance which has been strongly suspected by certain observers at various periods



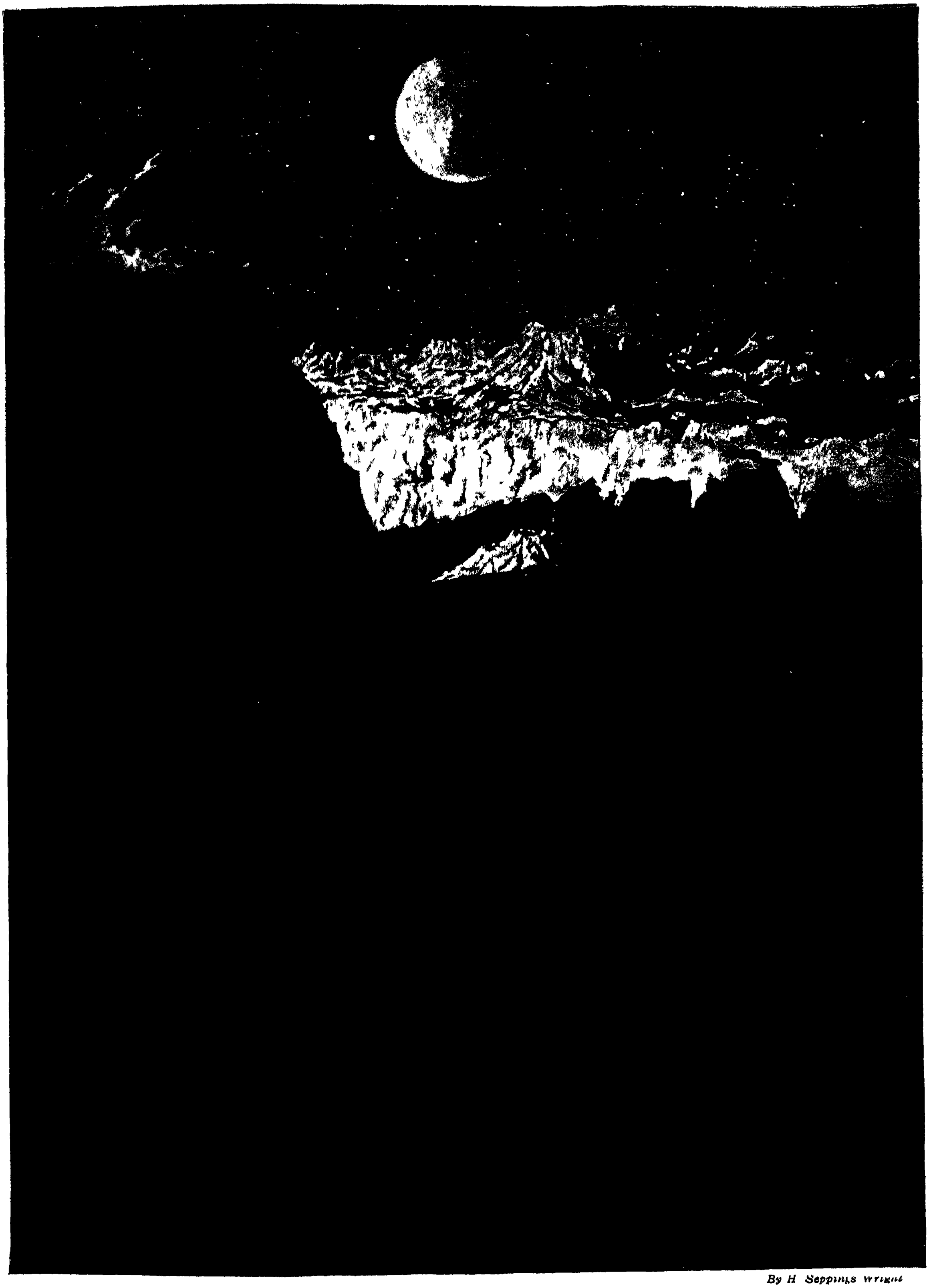
THE DARK SIDE OF VENUS

When Venus appears to us as a narrow crescent the " horns " of the latter are seen to extend beyond a half-circle This is due in part to the great apparent size of the Sun's disc as seen from Venus and in part to the bending of light by the planet's atmosphere At such times the whole of the disc of Venus has been dimly seen, like the " Old Moon in the New Moon's Arms " Some astronomers have considered this appearance an illusion, but the weight of evidence is in favour of its reality

Venus as the abode of living creatures has sometimes formed an alluring subject of discussion in works dealing with a plurality of worlds It is a question, however, that does not admit of settlement Probabilities, possibilities, and analogies may be referred to in detail, and inferences deduced from them, but our insufficient knowledge fails to conduct us to safe and certain conclusions

We are too apt to regard our own experiences and the conditions of our own globe as typical of the state of things existing or necessarily existing on other planets, but this is a faulty presumption which can only lead us astray The other planets of the Solar System are each one regulated and influenced by many circumstances of different character, and if life is sustained on various other orbs it is consistent with and suitably adapted to the conditions under which it is maintained

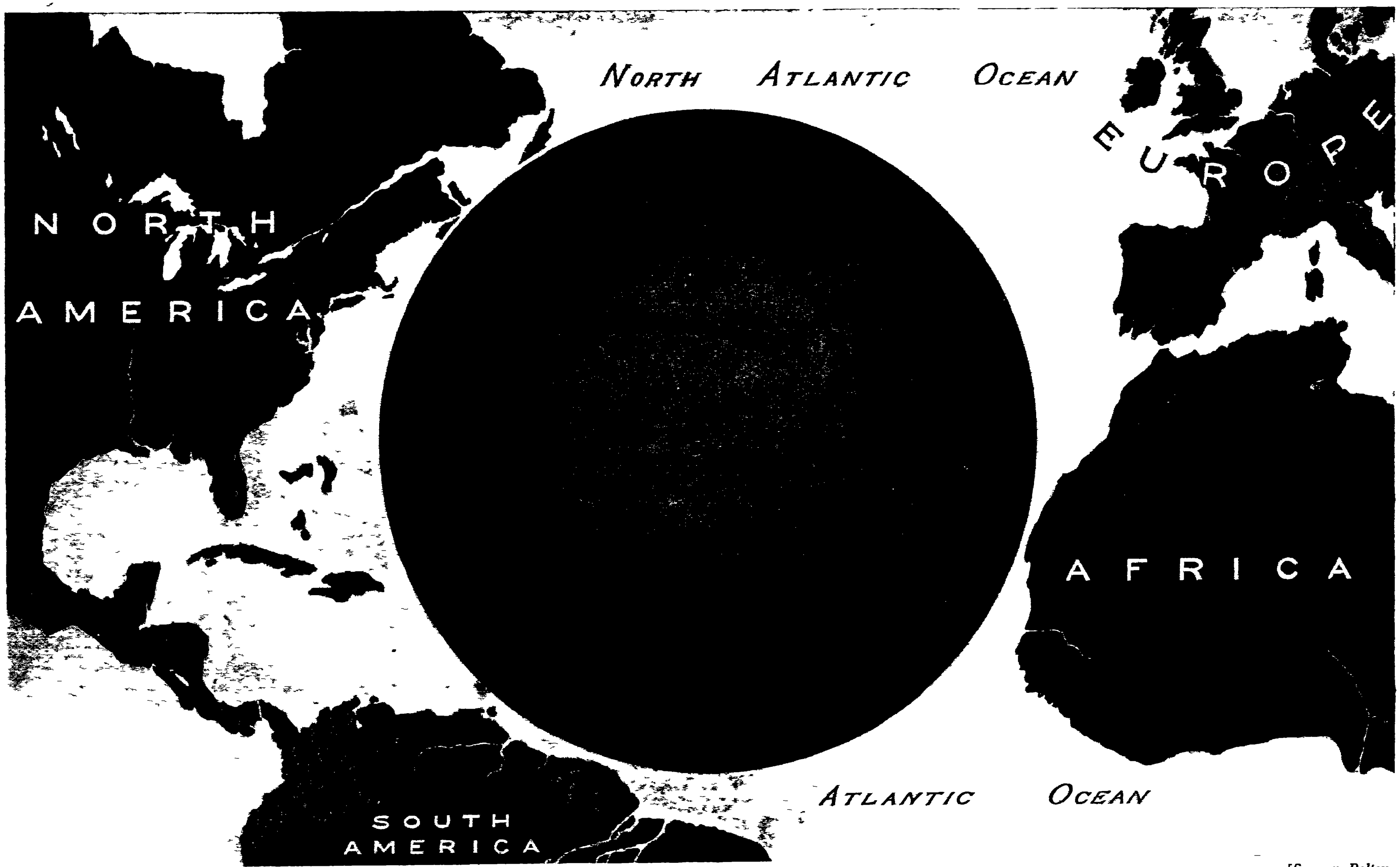
Mercury and Venus, so near the Sun, may well be able to withstand the great light and heat, sheltered and veiled, as their surfaces are, by dense atmospheric canopies On the other hand, Uranus and Neptune may be inhabited by animate beings able to thrive amid the cold and dark surroundings which are supposed to exist at such immense distances from the Sun Forming inferences from analogies we may reasonably conclude that our own little Earth is not the only orb favoured



By H Seppings Wright

A LANDSCAPE ON THE MOON

Here the Earth is shown in the Heavens as it would appear from its satellite the Moon It would be visible as a globe four times as large as the moon appears to us probably not quite so bright, except in the clouded portions, but shaded in various tones indicative of land water and vegetation The earth would pass through phases as the moon does but in the inverse direction There being no appreciable atmosphere the moon's sky would be quite black, the stars being visible at all times The sun would present a most splendid spectacle, the Corona and the large red prominences which we only see during the short time of an Eclipse of the Sun would also be constantly in evidence



Drawing by] [*Scriven Bolton*

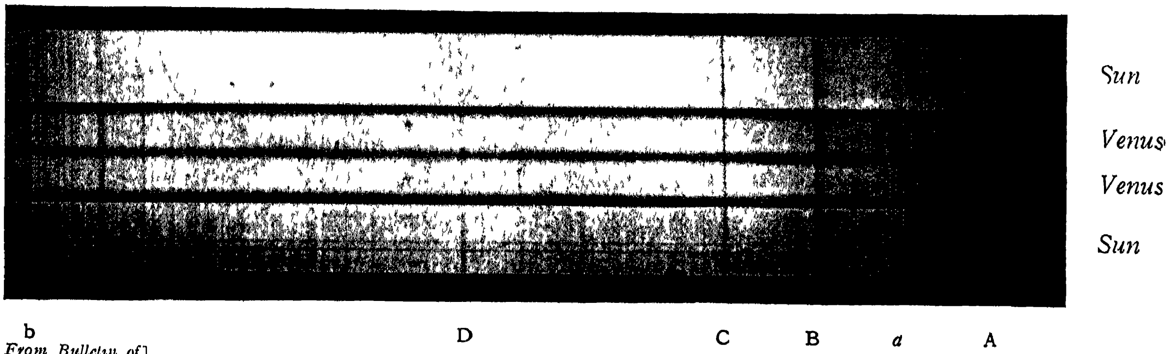
MERCURY AND THE ATLANTIC OCEAN

This illustration conveys to us a vivid idea of the comparatively small size of the planet Mercury His diameter, which is just on 3,000 miles, is nearly the same as that of the largest circle that could be drawn on a map of the Atlantic without touching any of the great continents Our Moon, of course, is smaller still, and would be represented as to its size by a circle that would almost fit into that portion of Africa which is included in the map above It would take nearly thirty Mercurys to outweigh the Earth in a giant balance

Drawing by] [*Scriven Bolton*

A RECENT THEORY OF THE ROTATION OF VENUS

In January 1921, Professor W. H. Pickering observed on Venus a series of large dark patches. These appeared to move in a direction nearly at right angles to that in which the planet had generally been assumed to rotate. Professor Pickering's conclusion was that the axis of the planet lay nearly in the plane of its orbit round the Sun, and that a complete rotation occupied sixty eight hours. Unfortunately the dusky patches, which were probably an effect of the atmosphere of Venus, disappeared after a few days, and no verification of the new theory has been possible.



From Bulletin of] [Lowell Observatory

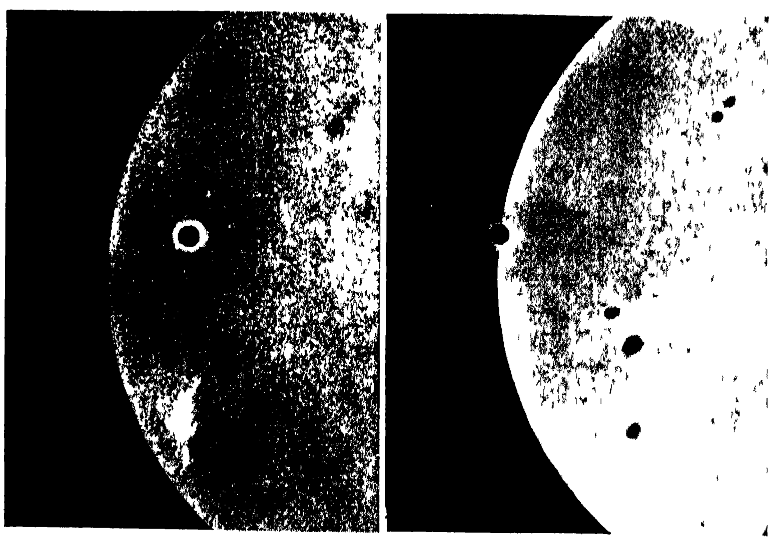
IS THERE OXYGEN ON VENUS?

Here we have a spectroscopic comparison of the light of Venus and the Sun, to both of which is added equally the absorbing effects of gases in our own atmosphere. The lines marked B and A are due to oxygen and water vapour respectively. If these substances were present in the outer parts of the atmosphere of Venus we should expect to find their lines more marked in the planet's spectrum than in that of the Sun. In actual fact, no such enhancement is observed, but this does not preclude the possible existence of oxygen and water vapour at lower levels in the planet's atmosphere.

with intelligent beings. Certain planets may not yet have reached the habitable stage, while others, like the Moon, may have passed it. It seems likely that the larger planets become habitable after longer periods, as they require more time for developments than the smaller ones. The worlds of space, like individual creatures, have their youth, maturity, and old age.

Venus possesses no satellite, though one was thought to have been discovered by several observers, chiefly in the Seventeenth Century. The supposed moon was confidently asserted to exist for a secondary orb, in which the phase of Venus had its duplication, sometimes appeared close to that planet and apparently accompanied her in her orbit. The alleged discovery aroused great interest and disputation, for there were many observers who failed to perceive any satellite though every effort had been made to find the elusive object.

The passage of time eventually settled the problem for it brought no further evidence of a satellite. The great modern telescopes and all the observational talent of the Nineteenth Century failed to reveal the supposed moon to Venus. So it has been finally put on one side, and its explanation is that it was one of the mythical objects seen in the faulty telescopes and by the imperfect observations of past generations. No doubt the satellite was either a bordering star or a spectral appearance or false image brought into being by imperfect instrumental adjustment. The Gregorian reflectors were occasionally apt to induce double reflections either by the mirrors or eyepieces, and observers, keen and ever alert in seeking for new objects, might well be allured into false presumptions by the fictitious creations alluded to.

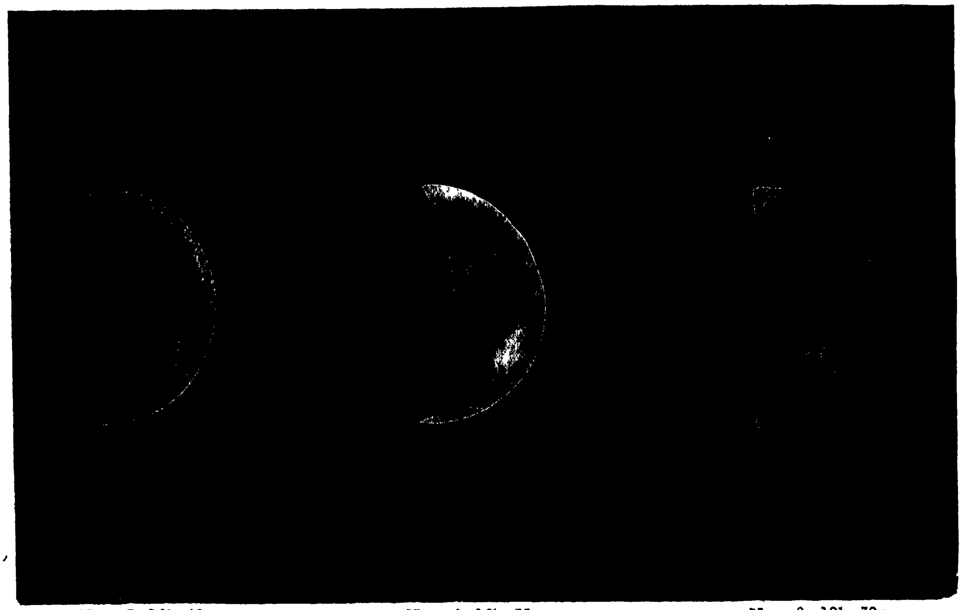


THE ATMOSPHERE OF VENUS

When Venus passes between Earth and Sun she is seen to be surrounded by a bright ring of soft light. This is, perhaps, the best proof we have of the existence of an atmosphere enveloping the planet.

As already explained in Chapter II, observations of Venus when she is projected as a dark spot in transit across the Sun, and her apparent track measured from two different stations, enable the Sun's distance to be ascertained. This was originally found by Encke in 1824 from observations made during the transits of 1761 and 1769 to be about 95,000,000 miles. The value was accepted for more than a generation until Hansen, in 1854, and Le Verrier, a few years later, reinvestigated the problem, and concluded the distance to be decidedly too great.

The transits in 1874 and 1882 afforded corroboration of the smaller distance, but other and preferable methods had been adopted, and Gill, in 1877, from observations of Mars, deduced a distance of 93,080,000 miles. The best and latest determination, however, is that of Hinks in **1910**, from observations of the minor planet Eros, which approaches the Earth nearer than the planets Venus or Mars, and this gave the distance of the Sun as 92,830,000 miles. Astronomers regard this element as of high importance, because it is a fundamental or basic one on which our knowledge of the distances, dimensions, &c., of the bodies composing our Solar System depends. It is therefore very satisfactory



Nov 5, 18h 49m — Nov 6, 18h 55m — Nov 8, 19h 30m

Drawing by] [*W F Denning*

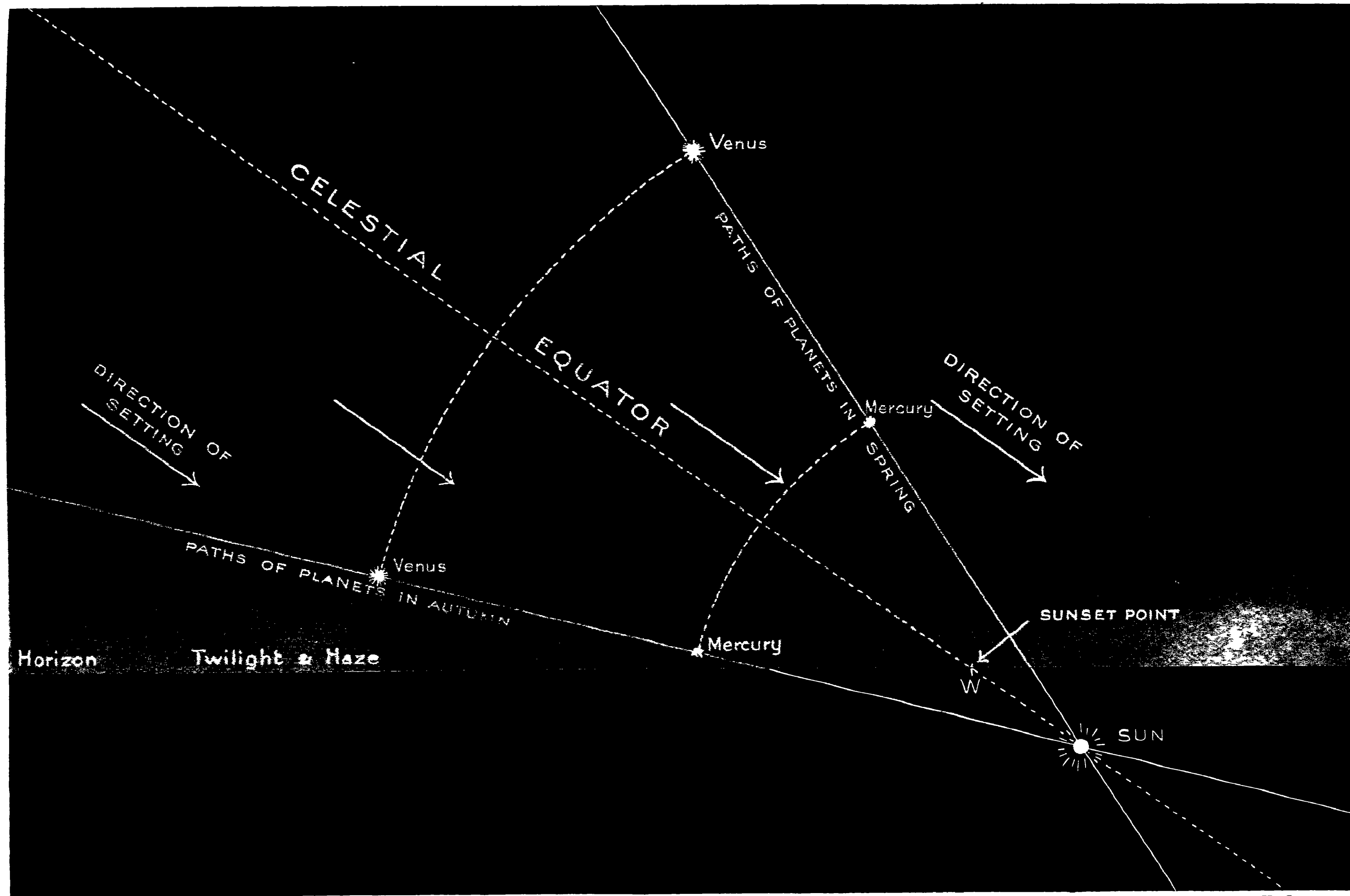
MERCURY IN 1881

For many reasons Mercury is a difficult object for telescopic study, but, under favourable conditions, markings are definitely observable on his surface. They generally take the form of dusky bands or patches, but can seldom be seen and identified often enough to give a reliable value of the planet's rotation

to realise that it has now been worked out in a very accurate manner and that it admits of very little if any correction. Transits of Venus occur at regular intervals of 8 $121\frac{1}{2}$, 8 $105\frac{1}{2}$, 8 $121\frac{1}{2}$ years, *et seq*. The dates of some past and future transits are —

Dec 6, 1631	Dec 8, 1874	Dec 10, 2117
Dec 4, 1639	Dec 6, 1882	Dec 8, 2125
June 6, 1761	June 8, 2004	June 11, 2247
June 3, 1769	June 6, 2012	June 8, 2255

There are certain naked eye observations which offer special attractions to celestial students, and particularly to that class not possessing telescopes to aid natural vision. To see Venus in sunshine is one of these; looking for the crescent of Venus is another, and these may be dismissed with the remark that the former feat is easily attainable, while the latter is beyond the capability of the naked eye. Among interesting telescopic observations may be mentioned a view of Venus when she is in inferior conjunction. At such times her whole disc has occasionally been perceived

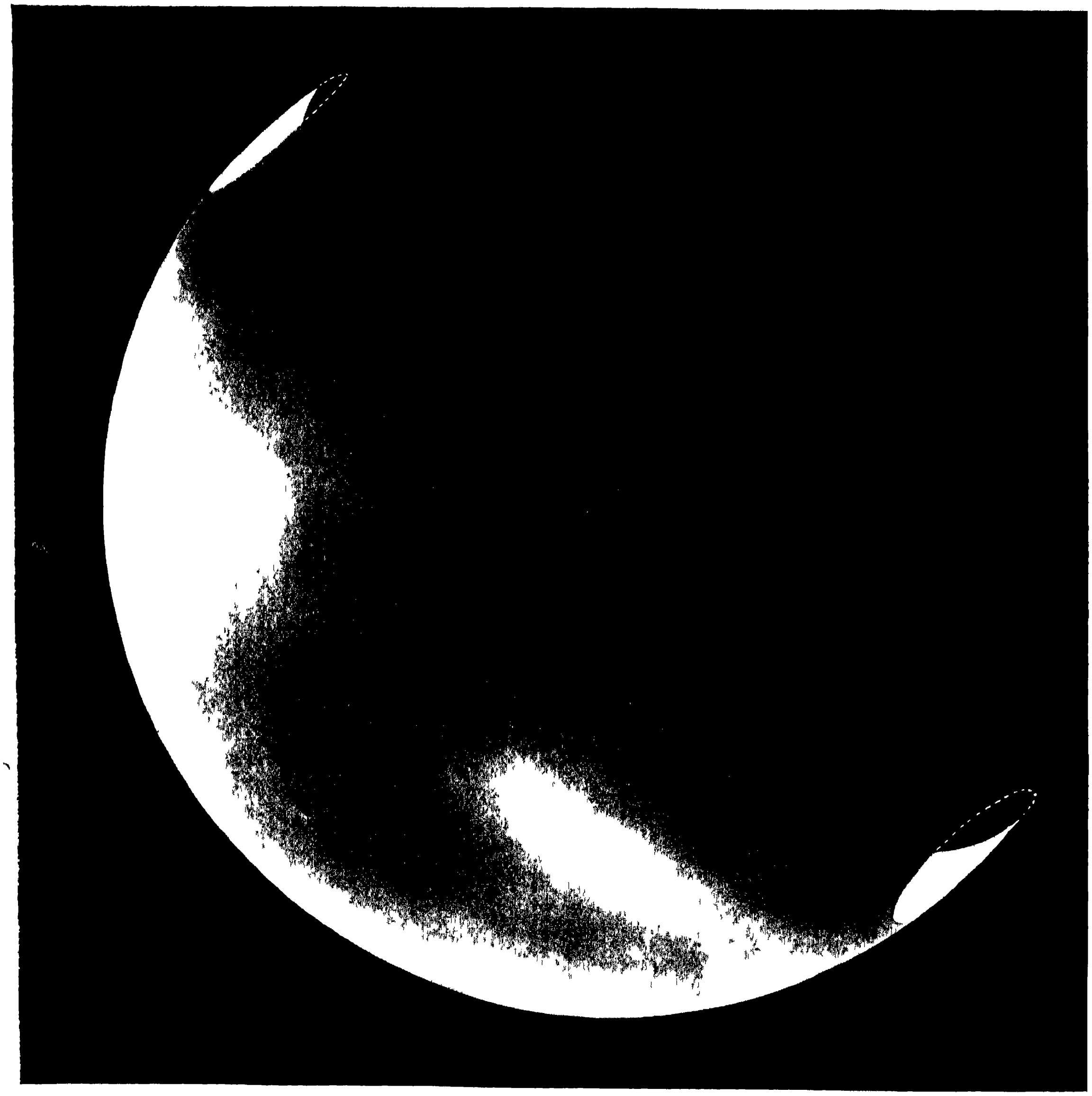


From a Drawing by] [*W H Steavenson*

"EVENING STARS" IN SPRING AND AUTUMN

When Venus and Mercury are east of the Sun they set later than that body and become visible in the western twilight as "evening stars" When this occurs in the spring the planets, being north of the celestial equator, will be quite high in the sky at sunset but in the autumn, as will be seen from the diagram, they will be much lower down, so as to be involved in twilight and haze near the horizon, they then set before it is at all dark, and are therefore not so conspicuously visible as in spring

in a good telescope, and the phenomenon has been termed "the phosphorescence of the dark side" The fact of its visibility has been disputed but negative evidence, though it often supplies a necessary corrective, is not always dependable Corroborative evidence has lately been furnished by almost simultaneous observations of the phenomenon by Mr Sargent at the Durham Observatory in 1922, and by Professor Duncan of the Whitin Observatory, Wellesley, Mass , on the following day, when "the planet was easily seen as a complete ring of light" The old controversy relating to the alleged satellite of Venus is hardly likely to come prominently to the front again, and the observations of Schroter, indicating mountains about twenty miles in height, will scarcely be duplicated with modern



THE BRIGHT "HORNS" OF VENUS

When Venus appears either as a half moon or a thick crescent, the telescope often reveals to us a well defined white patch at either "cusp" It has been suggested that these white patches may actually be the snow-covered polar regions of the planet, reflecting the sunlight more strongly than other parts of her surface The white dotted lines represent the unilluminated portions of these assumed polar snows Some astronomers have attributed the white patches to "phase effects," that is, appearances produced by the angle at which the sunlight falls on different parts of the planet

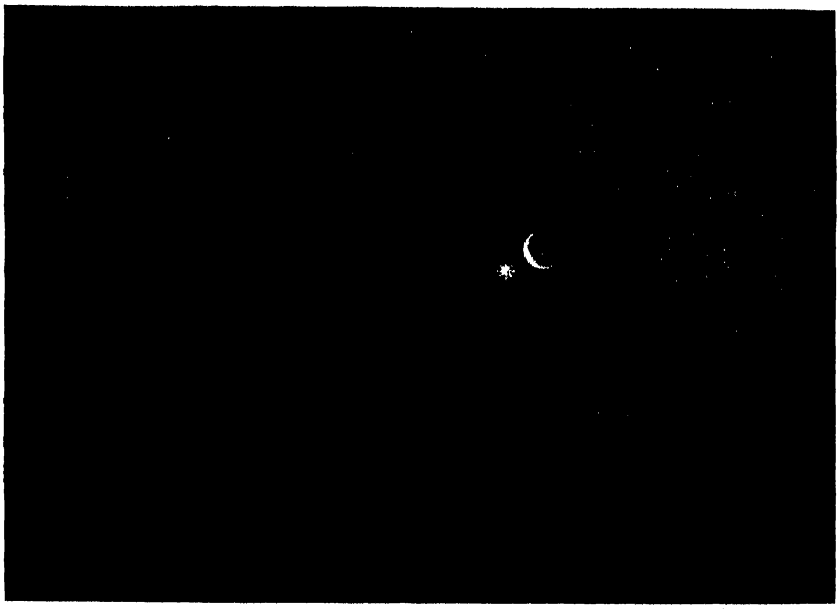
telescopes, though history has a peculiar tendency to repeat itself even in the sphere of Astronomy Observers of this planet must be cautious in discriminating between real and illusory objects and appearances when examining so brilliant an object after dark, for double reflection, flare, &c , are easily formed, and the judgment may readily err unless proper precautions are taken and suitable tests applied

CHAPTER V

THE EARTH-MOON SYSTEM

BY A C D CROMMELIN, B A , D Sc , F R A S

MY task in this chapter is to describe the little system that is made up of two bodies, the Earth and Moon, each influencing and influenced by the other in many ways There is no other system within our knowledge that closely resembles it The mass of the Earth is eighty-one times that of the Moon, whereas in all the other satellite systems the mass of the planet is thousands of times as great as that of its largest attendant



From] [" *L'Astronomie* "

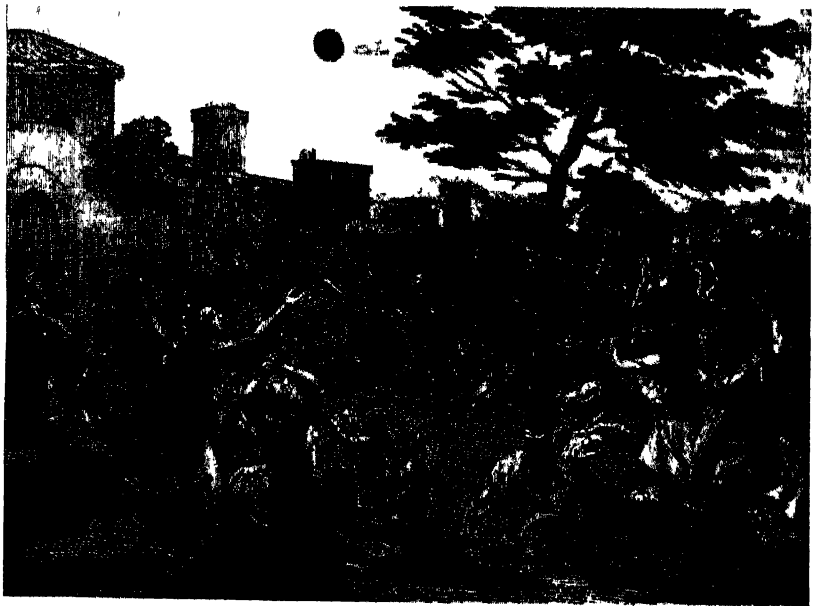
VENUS AND THE MOON, 1921, JULY 2

Conjunctions of Venus and the Moon, especially when the latter is in the crescent phase, always form an attractive spectacle At such conjunctions the Moon generally passes above or below the planet, but on this occasion, shortly after this drawing was made, our satellite passed directly in front of Venus, hiding her from view for over an hour

When men learnt that the place of our Earth in the universe was a less central and important one than they had previously imagined, it must have been some solace to their pride to realise that there was still one faithful orb that continued to own obedience to the Earth's sway This orb was also by far the most useful to man of all the heavenly orbs after the Sun As the lesser of the " two great lights " it served periodically to lighten the darkness of night , while its monthly changes of form, combined with the annual march of the seasons, gave those two important measures of time, the month and the year The function of a tide-raiser, which we now regard as the most important of the Moon's functions, was slow in being recognised, since early navigation was chiefly confined to the almost tideless Mediterranean

The Moon is our nearest neighbour among the heavenly bodies , its average distance is 239,000 miles, thirty times the diameter of the Earth, and but nine times its circumference Its distance can be found very accurately by observing it at the same time at distant stations, such as Greenwich and the Cape of Good Hope It is possible to find the distance from measures made at a single station, some when the Moon is low down in the sky, others when it is high up , this involves a knowledge of the Moon's motion between the observations , but it was not too difficult for the ancient Greeks, who obtained an estimate of the distance quite close to the truth

The following is a rough outline sketch of a process by which the distance may be found It was noted in the eclipse of the Sun of April 1912 that both Sun and Moon appeared of the same size, and that while one-twelfth of the Sun remained uncovered in London, the Moon just covered the Sun in Paris Thus motion through 200 miles sufficed to shift the Moon through one-twelfth of her diameter This gives the rough value 2,400 miles for the Moon's diameter, it is not very far from the true value—2,160 miles When we know the true size of the Moon, its distance follows at once, we can put a small disc, such as a coin, in a slot on a rod, and find the distance at which the coin just covers the Moon This proves to be 111 times the width of the coin Multiply the diameter, 2,160 miles, by the same number, and we get the distance as 239,000 miles Another very ingenious way of finding the distance was used by the ancients, they knew that the Sun appeared to be half a degree in diameter, and hence they saw that the edges of the Earth's shadow must slope inward, making angles of a quarter of a degree with the axis of the shadow If then they observed the size of the Earth's shadow where the Moon crossed it in lunar eclipses, they could calculate the Moon's distance



From "Astronomy for All"] [*By permission of Messrs Cassell & Co, Ltd*

CEREMONIES AMONG THE PERUVIAN NATIVES AT AN ECLIPSE

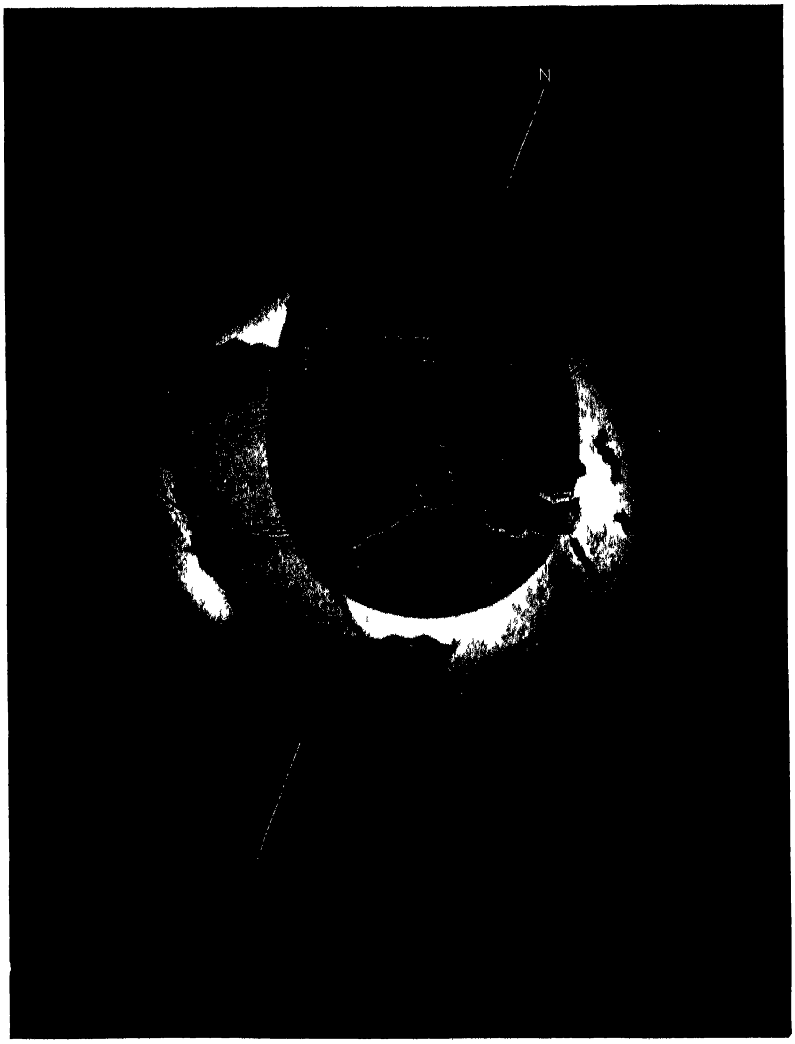
In former times it was often imagined that eclipses were caused by some malign being, such as a dragon, devouring the luminary, various ceremonies were performed in the hope of driving away the evil influence It is one of the advantages of astronomical knowledge that we can contemplate these grand observances without panic

It was next found that the Moon's distance is not constant, but alternately increases and diminishes by some 13,000 miles above or below the average value Also it moves quicker when near the Earth than when far from it The next step was to compare its path among the stars with that of the Sun The latter path has long been accurately known, and the name Ecliptic has been given to it (probably because eclipses can only happen when the Moon is quite close to it) It was found that the Moon's path does not coincide with the Sun's, but makes an angle of more than five degrees with it (This is the angle between the stars Castor and Pollux in the Twins, or between the two pointer-stars in the Great Bear)

Half of the Moon's path lies to the north of the ecliptic, the other half to the south, there are two crossing points, now known as the nodes, but in earlier times called by the fanciful titles of the "Dragon's Head" and the "Dragon's Tail" These names were probably derived from the myth that in eclipses the luminary affected was being devoured by a dragon, various ceremonies were enacted in the hope of driving this evil beast away, and the reappearance of the orb was hailed as a victory for these rites

As soon as eclipses began to be noted with care, it was seen that they are liable to happen at two seasons of the year about six months apart (the times when the Sun is passing the two nodes), and further that these seasons do not recur at the same time in successive years, but gradually get earlier For example, in 1919 there were eclipses in May and November, in 1923 they occur in March and September, while in 1927 the latter season will have gone back to June, giving, in fact, the British

total solar eclipse of June 29, 1927 This persistent regression of the eclipse seasons implies that the plane or level in which the Moon travels round the Earth is constantly shifting, the nodes or crossing points go right round the sky in eighteen and a half years This shift is one of the many disturbances which the Sun produces in the Moon's motion round the Earth If only two orbs existed, the path of one round the other would be a simple ellipse, always keeping in the same position But if a third orb is introduced, this simplicity is destroyed, and various changes take place in the orbit For example, the Sun's disturbing action causes the long axis of the Moon's orbit to move forward, making an entire circuit in eight years and ten months The amount of eccentricity also changes It is greatest when the long axis points towards the Sun or in the opposite direction, it then amounts to one-fifteenth, it is smallest when the long axis points square to the Sun's direction, being then one-twenty-third The amount of tilt of the Moon's orbit to the ecliptic is also varying, it is greatest when the Sun is at either node, amounting to 5° 18′ It falls to 5° 0′ when the Sun is mid-way between the nodes We shall refer to one or two other disturbances produced by the Sun, actually many hundreds of them are known, which makes the calculation of the Moon's motion an extremely complex matter

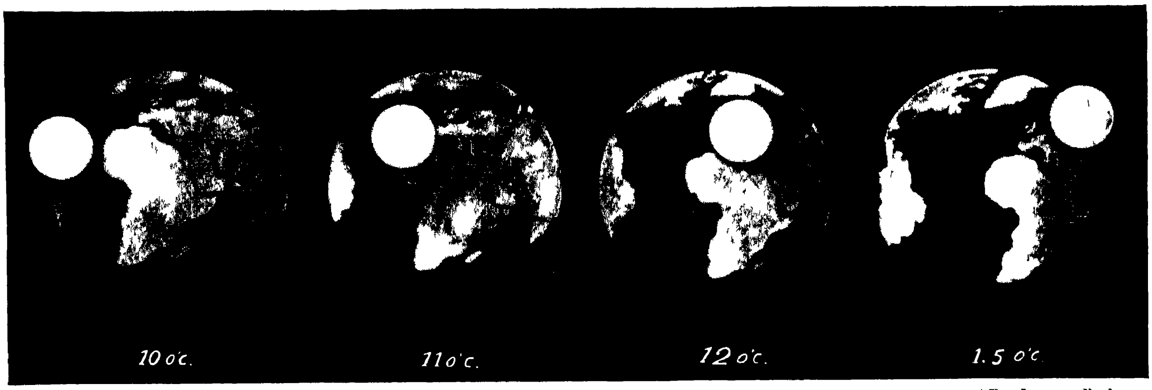


[By the Abbé Moreux

PATH OF THE MOON'S SHADOW IN THE ECLIPSE OF APRIL 17, 1912

People on the dark line through Brazil, Spain, France, Germany, Russia, saw the Moon cover the Sun centrally, those for some distance on each side of this line saw a partial eclipse, the shading in the picture exaggerates the slight gloom of these regions, which diminishes as we pass from the central line

To return to the backward motion of the nodes, without introducing mathematics, it is not difficult to see that there is a tendency on the part of the Sun to pull the Moon down into the plane in which the Earth is moving, but the fact of the Moon's continual motion prevents the plane of her orbit from being forced down into the ecliptic, what happens is that the Moon reaches the plane of the ecliptic a little sooner than it would do if the Sun were not acting, in other words, the node is made to move backwards to meet the Moon The action goes on month after month in the same direction, the result being a backward movement of the nodes of nineteen and a half degrees per year Each time that the Sun passes either node (that is at intervals of slightly under six months) there must be at least one eclipse, and there



[By Lucien Rudaux

VIEW FROM THE SUN OF THE ECLIPSE OF APRIL 17, 1912

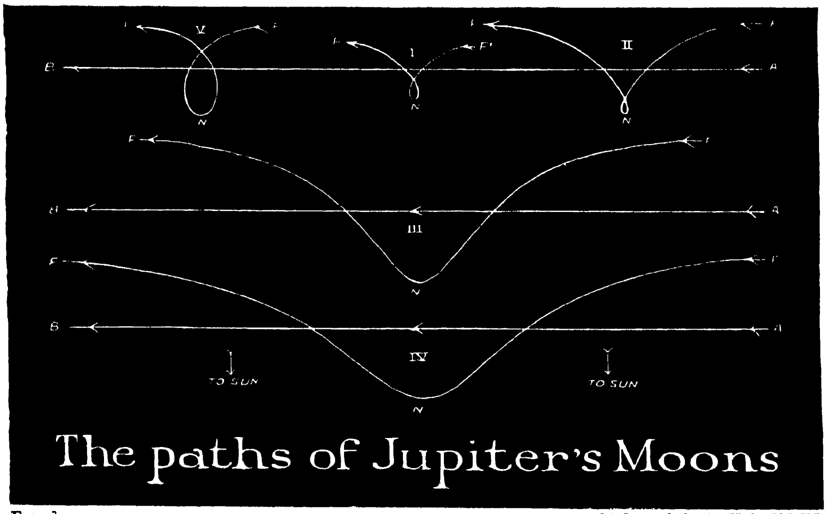
An observer at the middle of the Sun would have seen the Moon pass in front of the Earth, the regions behind the Moon's centre would see a central eclipse, those behind the rest of the Moon a partial one

may be three, in the latter case the middle one of the three is a total lunar eclipse, preceded and followed, a fortnight earlier and later, by partial solar ones It is possible to have three similar eclipses at the other node, just under six months later, the beginning of a third eclipse season may fall in the same calendar year, owing to the backward movement of the node, we thus get the maximum possible number of eclipses in a year to be seven they must be either five solar, two lunar, or four solar, three lunar Seven eclipses in a year is a very rare occurrence, it occurred in 1917, and will happen again in 1935

The least number of eclipses in a year is two, both central solar ones, as a rule one of them is total, the other annular, the latter eclipse happens when the Moon covers up the Sun centrally, but being in the farther part of her orbit, it does not look large enough to hide the whole of it, a ring (Latin *annulus*) of sunlight remains visible round the dark Moon

Annular eclipses happen rather more frequently than total ones, but they are much less important, adding very little to our knowledge of solar physics, total eclipses, on the other hand, afford the only opportunity of studying the faint outer appendages of the Sun, and expeditions have been sent to distant places to enjoy the brief minutes of totality (the maximum length possible is seven and three-quarter minutes) Photographic methods are used almost exclusively, giving much more reliable results than hurried visual ones

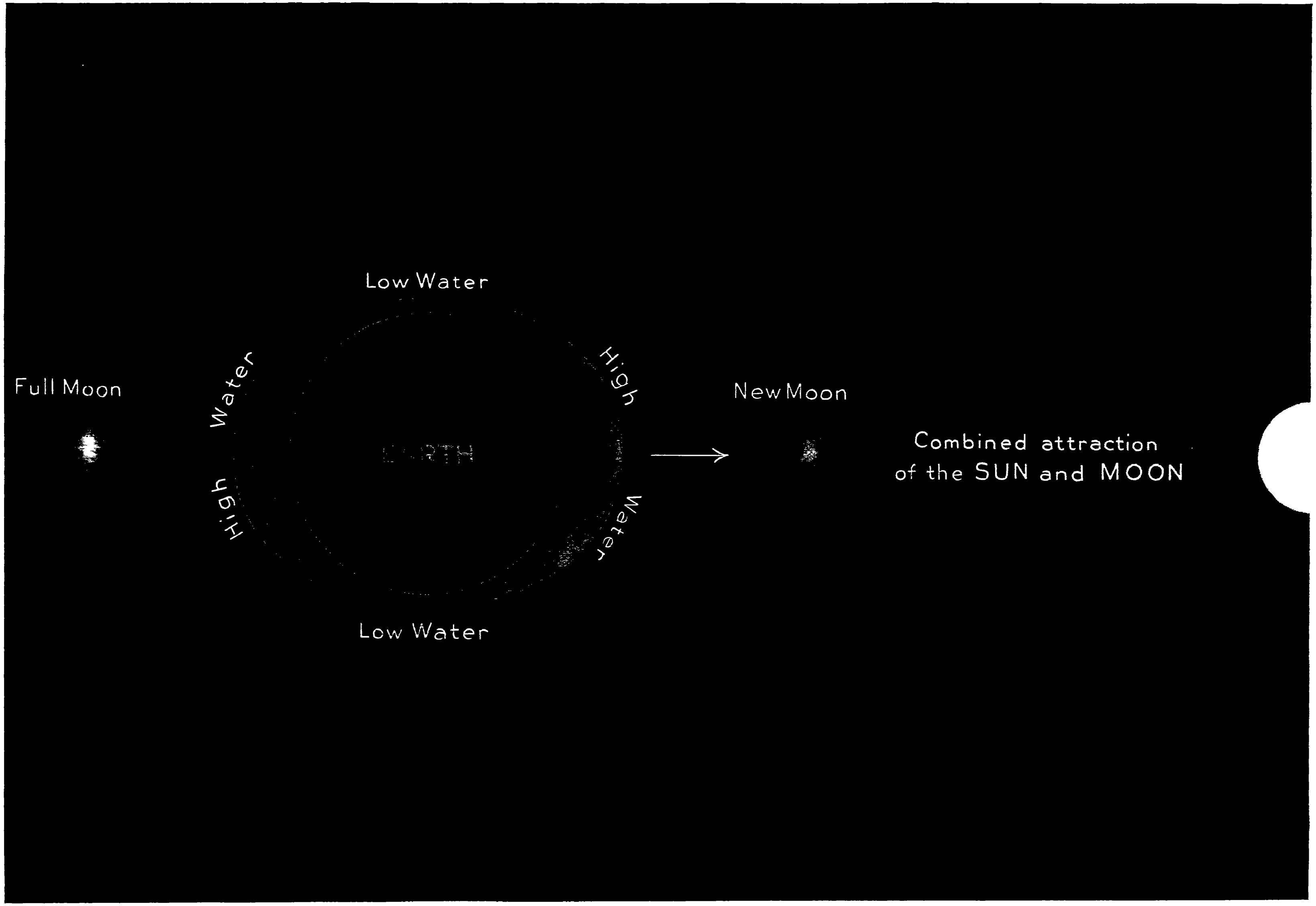
Total lunar eclipses, though less important than solar ones, are extremely beautiful phenomena Instead of its usual silvery light, the Moon's orb appears of a lurid, coppery hue It must be remembered that the Moon is then wholly in the Earth's shadow, and no direct



From] [' Knowledge," Vol XXVI

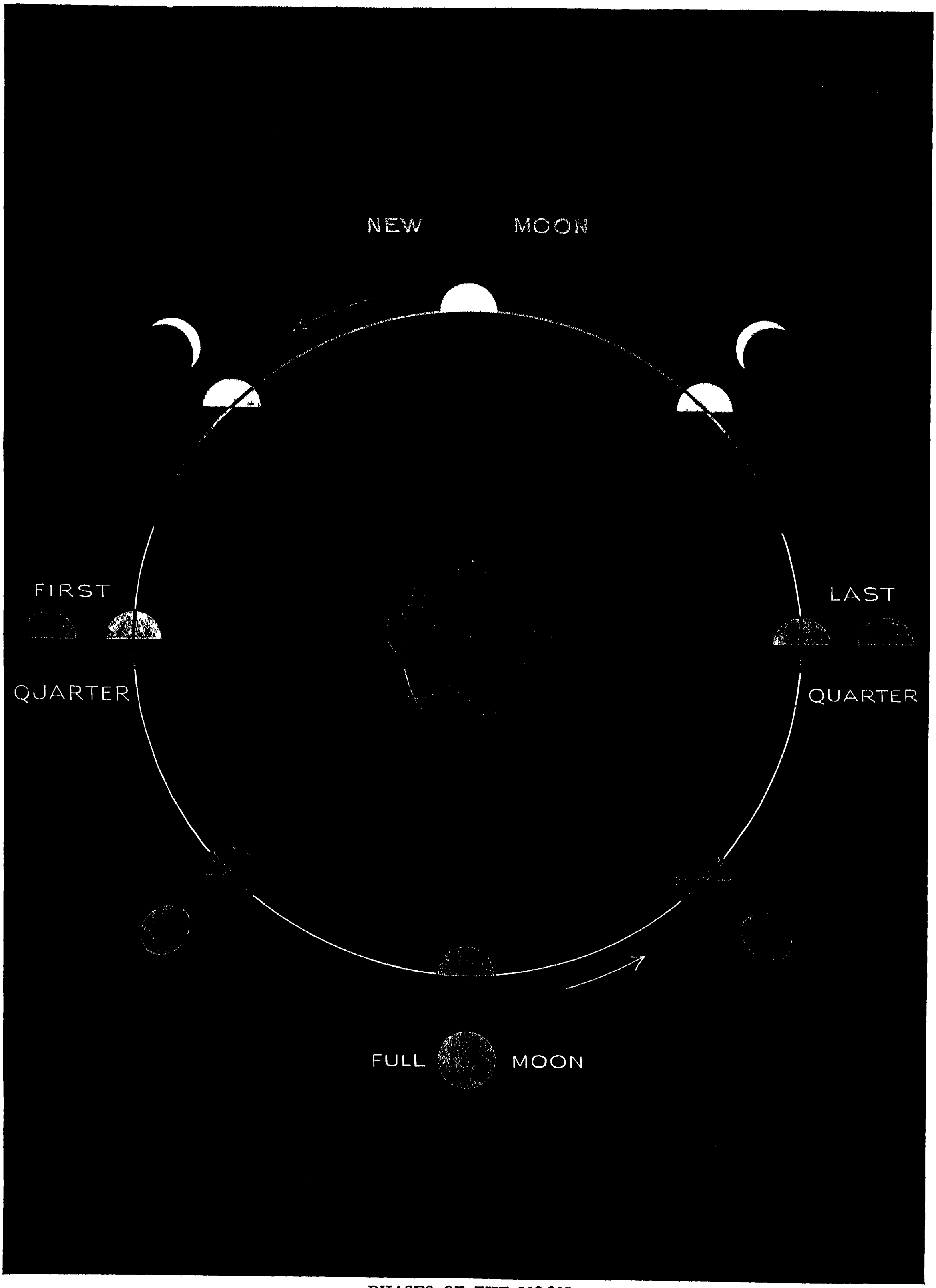
THE PATHS OF JUPITER'S MOONS

This picture (drawn by C T Whitmell) shows how greatly the movements of other satellites differ from that of our Moon, as the Figure on page 221 shows, it is always concave to the Sun, those of Jupiter's moons are notably convex to the Sun at New Moon



CAUSE OF SPRING TIDES

It is assumed, for simplicity, that Sun and Moon each produce high water at the point nearest them, and the opposite point Thus at New and Full Moon, when Sun, Moon, Earth, or Sun, Earth, Moon are in a line, the solar and lunar high waters come at the same points, the low waters midway between them, do the same, at these times we get extreme high tides, and also extreme low ones The reason of the accumulation at the side remote from Sun or Moon, is that the water here is less strongly pulled than the solid earth, and is, as it were, "left behind"

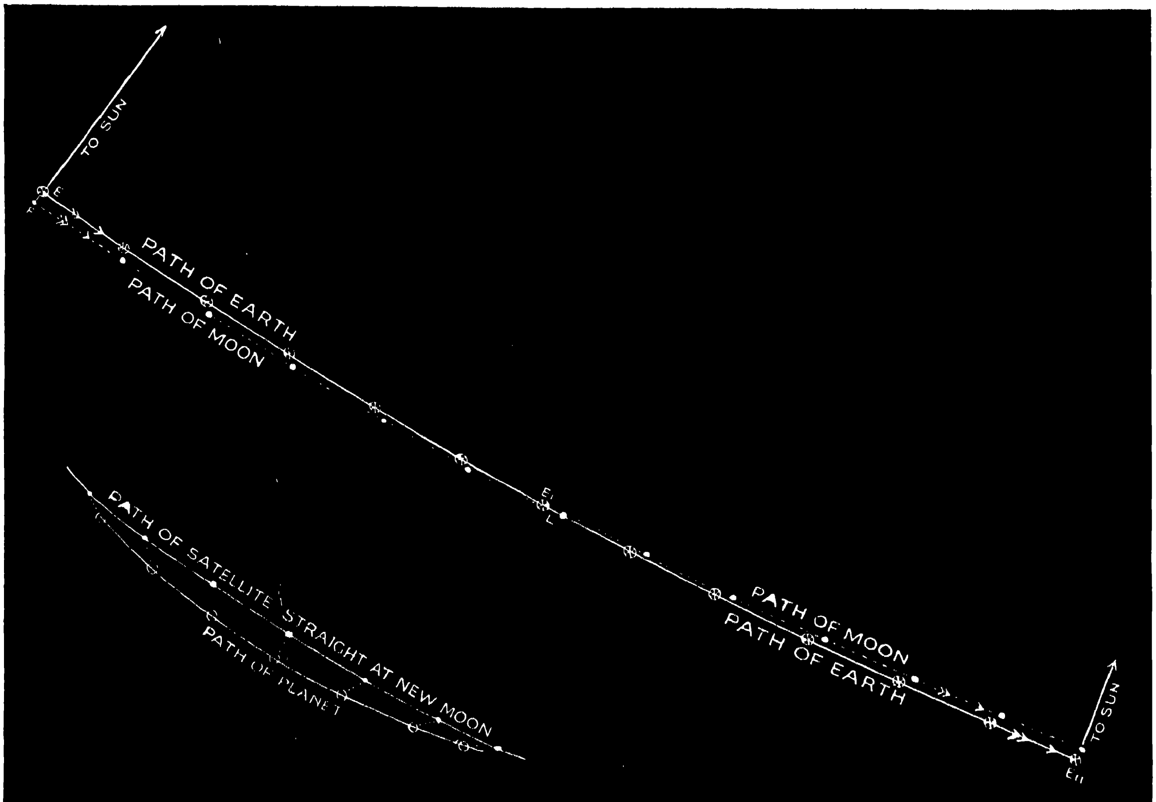


PHASES OF THE MOON

The Moon is a dark body that shines by reflected light from the Sun, half of it is bright, and half dark, when nearly between Earth and Sun, the dark side is towards us, and the Moon invisible As it moves on we see a little of the bright side, shaped like a crescent When it has gone a quarter of the way round, we see it half lit up, as it moves on we see more of the bright portion, the name Gibbous being used when it is more than half Full, when almost opposite to the Sun we see the whole bright side (Full Moon) except when it enters the Earth's shadow and is eclipsed, from Full to New the changes repeat themselves in the reverse order

sunlight can reach it The light that does reach it is bent or refracted by the lower layers of the Earth's atmosphere , it appears red for the same reason that the setting Sun does It was shown in the chapter on Light that sunlight consists of various waves of different lengths The short violet rays are the ones most easily stopped by any obstruction, such as thick air, while the long red waves have more penetrating power Now, the light that passes through the atmosphere to reach the eclipsed Moon has to make a double journey through our air, first coming from its outer layers down near the Earth's surface, and then passing out again Hence it is still more effectively reddened than the setting Sun

Mr L Richardson, who has made a careful study of lunar eclipses, finds that it is only the lower strata of our atmosphere that are effective in transmitting light to the eclipsed Moon , now these



From "Knowledge"] [*A C D Crommelin*

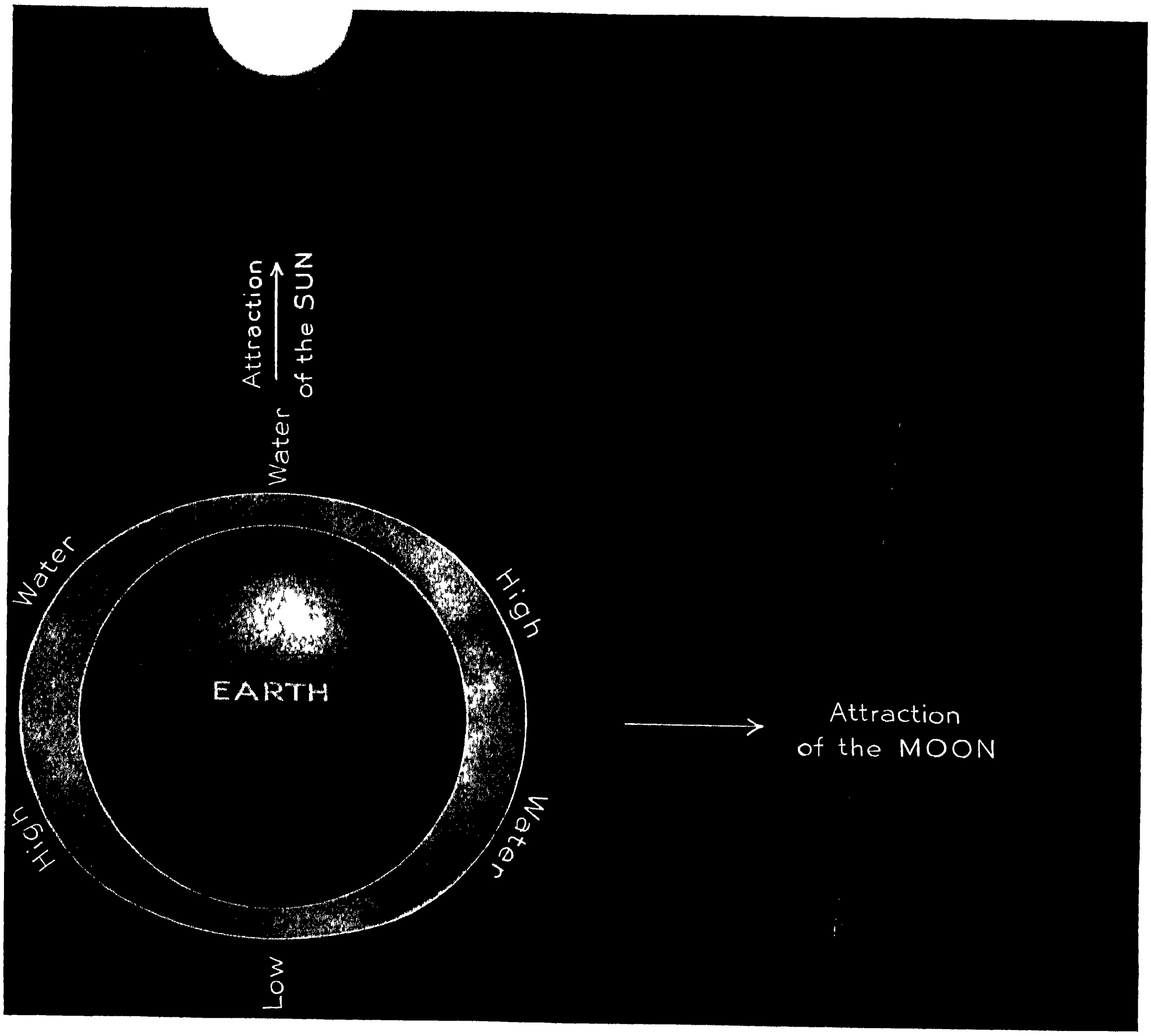
PATHS OF EARTH AND MOON ROUND SUN

The Sun's pull on the Moon is more than double the Earth's pull Consequently the Moon's path is always concave to the Sun It is, however, much more nearly straight at New Moon than at Full , it would be exactly straight at New if the Moon were at two-thirds of its actual distance (see lower diagram) The upper diagram shows the motion from Full to New, that is, for about fifteen days , the interval between the successive positions shown is one and a quarter days The whole of the Moon's path may be mapped out by simple repetition of the above diagram (alternately forwards and backwards) about twenty-five times

strata are liable to be rendered opaque by widespread cloud or haze , the amount of light seen on the eclipsed Moon gives a most useful idea of the general state of clearness of our atmosphere One of the darkest eclipses on record, that of October 1884, came at a time when the air was known to be full of fine dust from the Krakatoa eruption of 1883

There is a remarkable cycle, known as the Saros, after which eclipses recur with an almost exact reproduction of their details Its length is 223 lunations, amounting to eighteen years and eleven and one-third days when four leap-days intervene, and a day less when five leap-days intervene It is connected with the eighteen and a half years in which the Moon's nodes complete a circuit, but

also by a happy coincidence the distance of the Moon from the Earth, as also all the larger disturbances in her motion, recur practically unchanged. The cycle was known to the Chaldeans more than 2,000 years ago, and was indeed the earliest method of predicting eclipses. But the odd third of a day was a difficulty to them, since it means that the region of the Earth that sees a particular phase of the eclipse is shifted westward through a third of the Earth's circumference. In those days, when little of the Earth's surface was known, this meant that they had generally to wait for the triple Saros, or fifty-four years one month, after which the eclipse returned to the same longitude as at first.



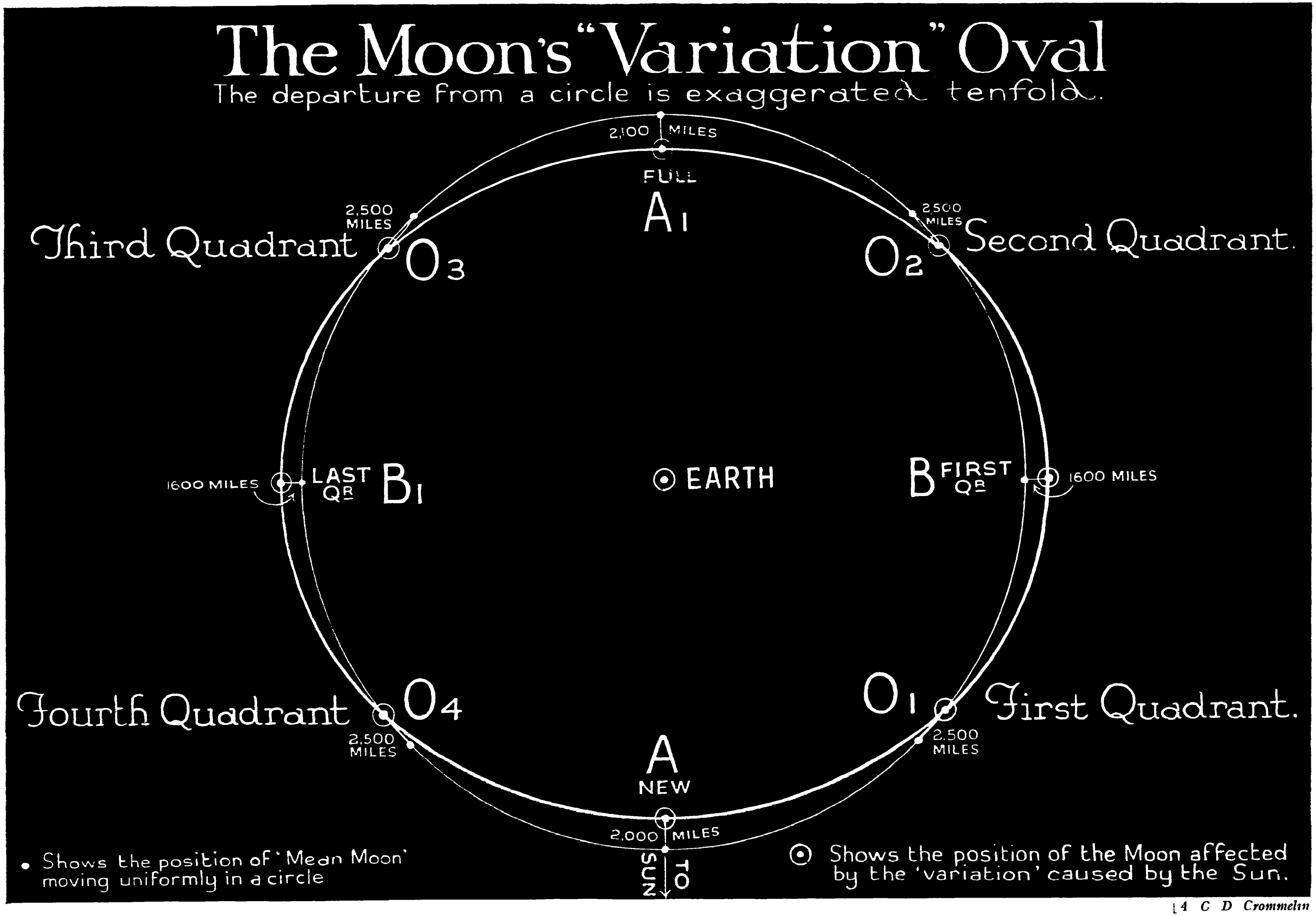
CAUSE OF NEAP TIDES

At First and Last Quarters of the Moon the lunar high water falls on the solar low water, and the lunar low on the solar high. Thus at the Quarters we get small tides, which neither rise high nor fall low.

As an instance of the Saros, we may take the coming eclipse in England in 1927; a Saros later, in July 1945, there will be a total eclipse in Norway in the afternoon. Three Saroses later still, on August 11, 1999, totality will again cross England (Cornwall).

The fact noted above that the maximum number of seven eclipses occurred in the years 1917–1935 is another instance of the Saros cycle.

The motion of the Moon's nodes produces quite a notable change in the conditions under which



[A C D Crommelin

THE VARIATION OVAL

This picture shows the manner in which the Sun would distort the Moon's path round the Earth if it were circular, it would squeeze it inwards at New and Full, outwards at the Quarters, the direction of the Moon is unaffected at New, Full, and the Quarters, the speed is greatest at New and Full, so that the Moon is 2,500 miles ahead of the undisturbed place at the middle of the first and third quadrants, it then begins to fall back, and at the middle of the second and fourth quadrants it is 2,500 miles behind the undisturbed place The whole oval is shifted bodily fifty miles towards the Sun, this shift enables us to get the Sun's distance by observing the Moon

[By A Twidle

PARTICLES OF THE MOON EXPELLED FROM THE EARTH BY SOLAR TIDES

Sir George Darwin's theory of the Moon's birth is illustrated on page 3 The artist of the present picture supposes that after leaving the Earth the particles that were to form the Moon circulated round the Earth in a ring somewhat like that of Saturn This is by no means certain, they may have remained in a fairly compact swarm from the first It appears that they cannot have consolidated into a single orb till they were some twelve thousand miles distant from the Earth

we see the Moon At one stage in the eighteen and a half year period the Moon's inclination of five degrees to the ecliptic is added on to the twenty-three and a half degrees which is the slope of the latter to the equator Thus the Moon wanders twenty-eight and a half degrees on each side of the equator, the full Moon of summer being very low down, and that of mid-winter being very high up This state of things occurred in 1913, the full Moon of December 24, 1912, attracted much attention from its unusual altitude, which happened to coincide with unusual nearness to the Earth, this, in addition to a clear sky, caused the intensity of moonlight to be quite beyond normal The high inclination of the Moon's orbit to the equator will recur in 1931, an opposite state of things prevailed in 1922 The inclination to the equator was then only eighteen degrees, so that its wanderings were confined within narrow limits, and it neither went very high nor very low

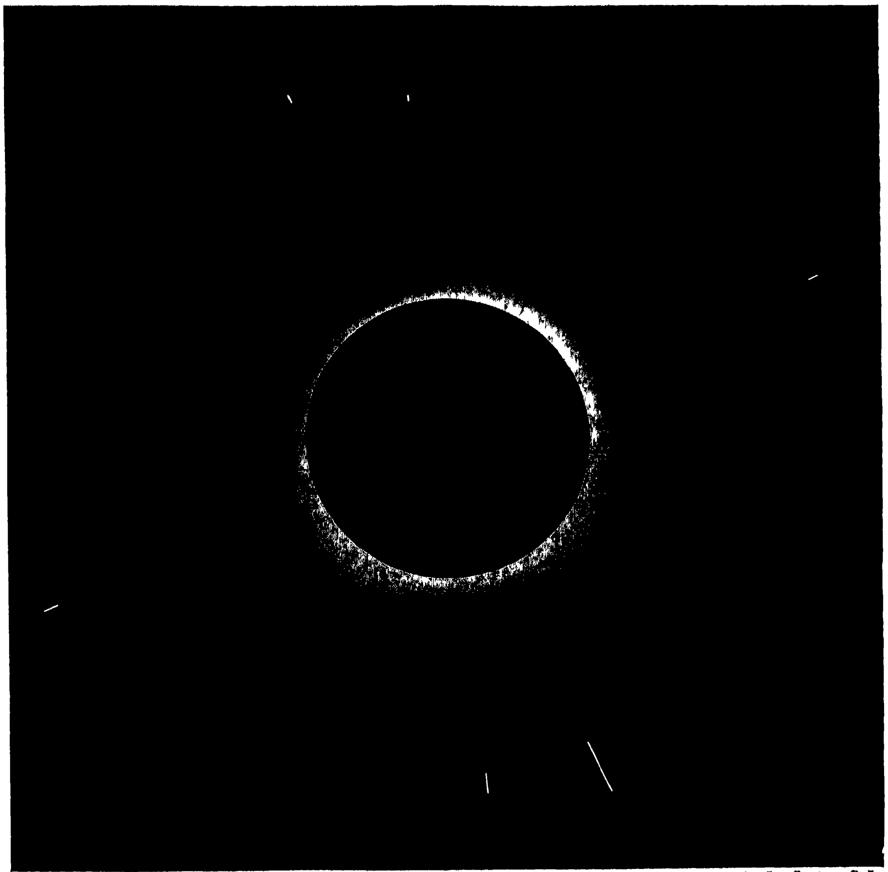


Photo by] [Rev A L Cortie, S J

THE ECLIPSE OF AUGUST 21, 1914, PHOTOGRAPHED AT HERNÖSAND, SWEDEN

This eclipse was notable for its occurrence in the first month of the War, which added to the difficulties of observers The Sun had just begun to revive from the notable minimum of 1913, and the type of corona was designated "intermediate" Note the "polar plumes" at the bottom

This seems an appropriate place to describe the phenomenon known as the Harvest Moon Many people have a vague notion that this Moon is for some reason brighter than any other The fact is merely that about the time of the autumn equinox the Full Moon is at the part of its orbit where it is moving north most rapidly, now on the average the Moon rises three-quarters of an hour later each day, this amount is increased when the Moon is moving south, and diminished when it is moving north But the phenomenon naturally attracts most attention when the Full Moon is moving rapidly north, for then it rises in the neighbourhood of sunset for several evenings in succession, and is available as a light-giver for all the working hours of the night Hence the Harvest Moon is the Full Moon that falls nearest to the autumn equinox (September 23) The phenomenon is most striking in those years in which the orbit is most inclined to the equator, thus the following times are taken from the almanac of September 1913 September 15 rises at 6 17 p m, September 16 rises at 6 25 p m, September 17 rises at 6 36 p m, September 18 rises at 6 46 p m, September 19 rises at 7 2 p m, September 20 rises at 7 19 p m It will be seen that the time of rising gets only an hour later in five days, on

the other hand, at the March Full Moon, when the Moon is moving south, the time of rising gets later by as much as one and a half hours each day

It is now time to enter more into detail on the manner in which the Sun disturbs the Moon's motion, the first fact we note is that the Sun's pull on the Moon is two and one-sixth times as great as the Earth's pull, at first sight it seems strange, under these circumstances, that the Moon should continue to move round the Earth, but we have to remember that the Sun is pulling both Earth and Moon, and making them go round it in company, it is merely the small difference between the two pulls (due to slightly different distance and direction) that is effective in disturbing the Moon's motion round the Earth Let us first examine the figure on page 221, which shows the shape of the Moon's path, produced by its two different circling motions It will be noticed that the path is everywhere concave to the Sun, this being indeed a necessary consequence of its superior pull There is, however, a much closer approach to straightness at New Moon than at Full Moon, if its distance from the Earth were only 160,000 miles (two-thirds of its actual distance) its path at New Moon would be straight; the Moon is the only satellite in the Solar System whose path is always concave to the Sun, in all other cases the pull of the planet exceeds that of the Sun It will be seen that a large scale is required to show the shape of the Moon's path round the Sun, it is only possible to

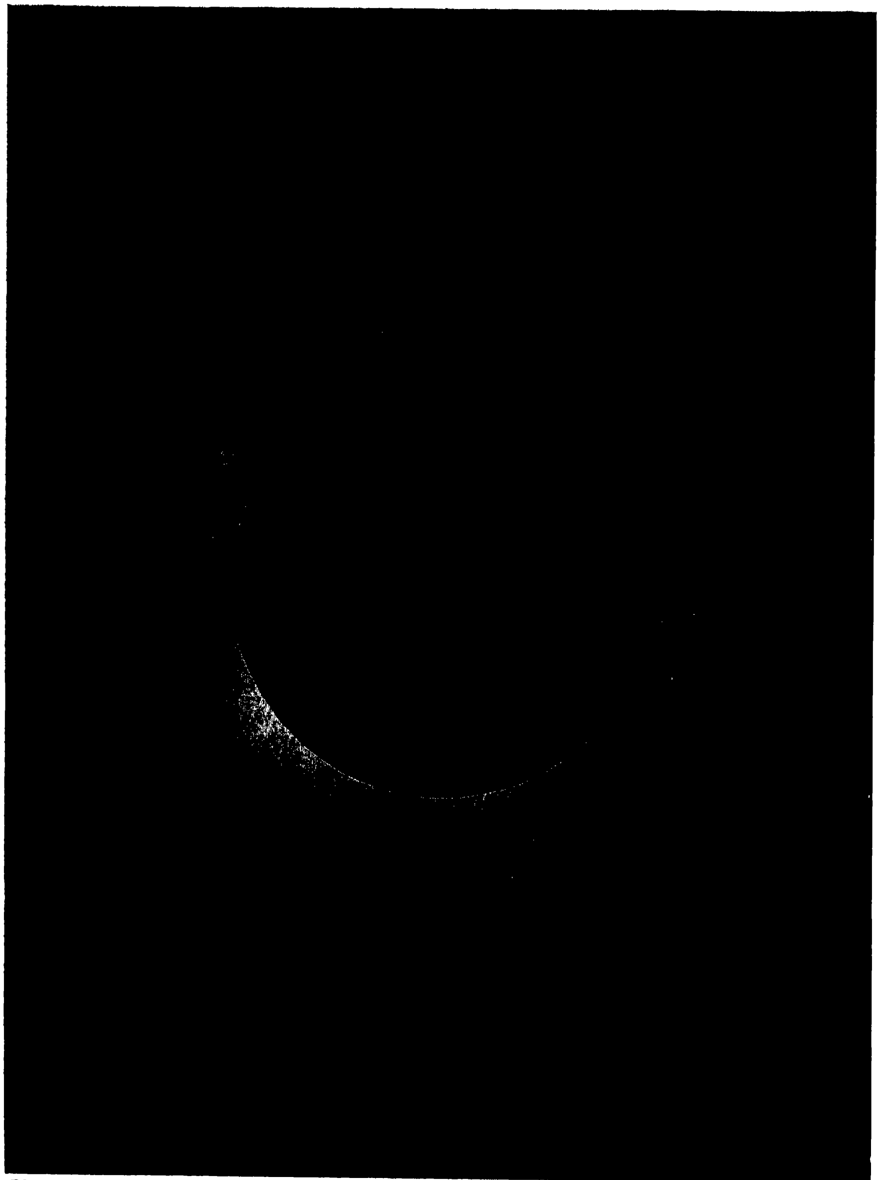
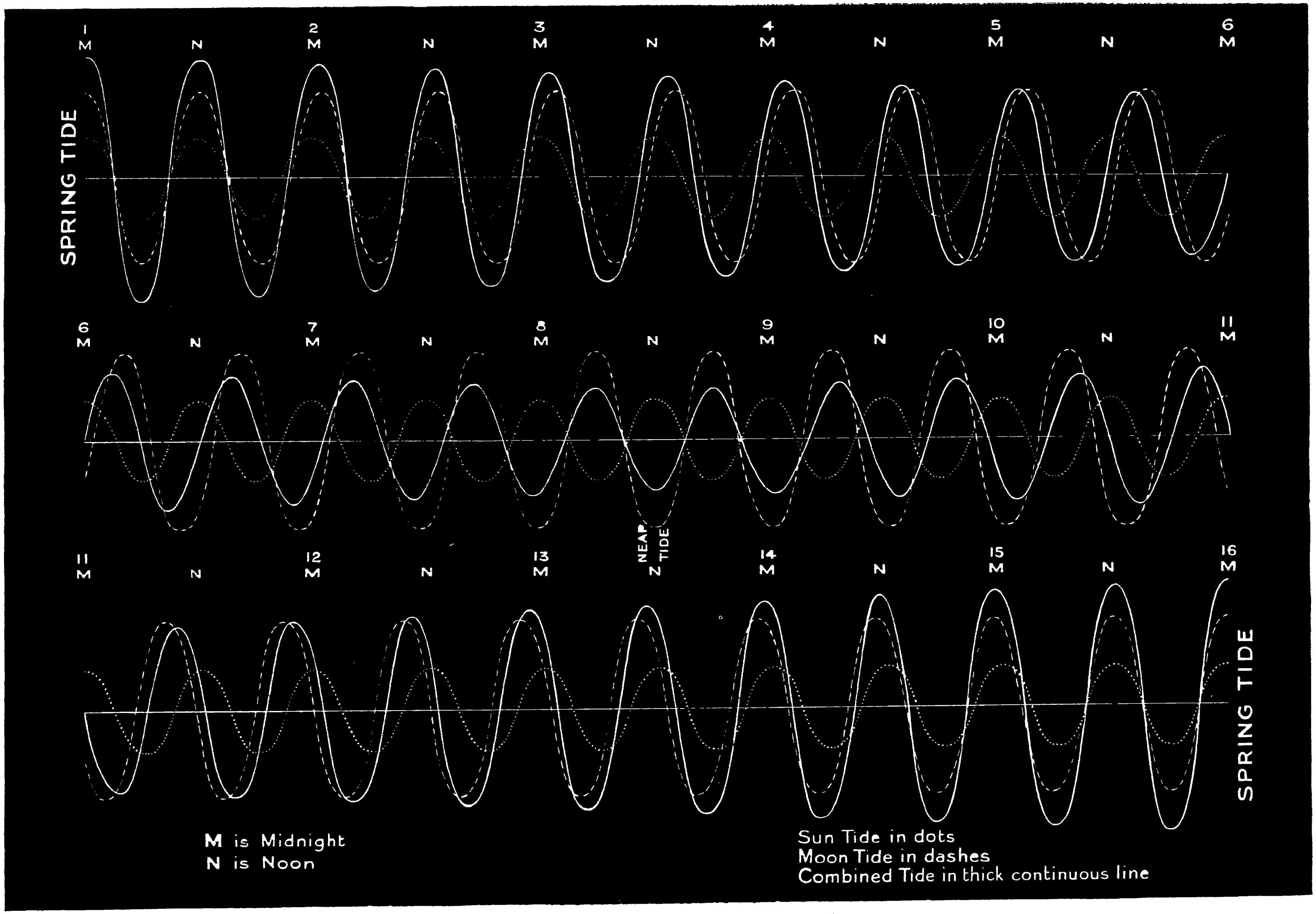


Photo by] [*A. C D Crommelin*

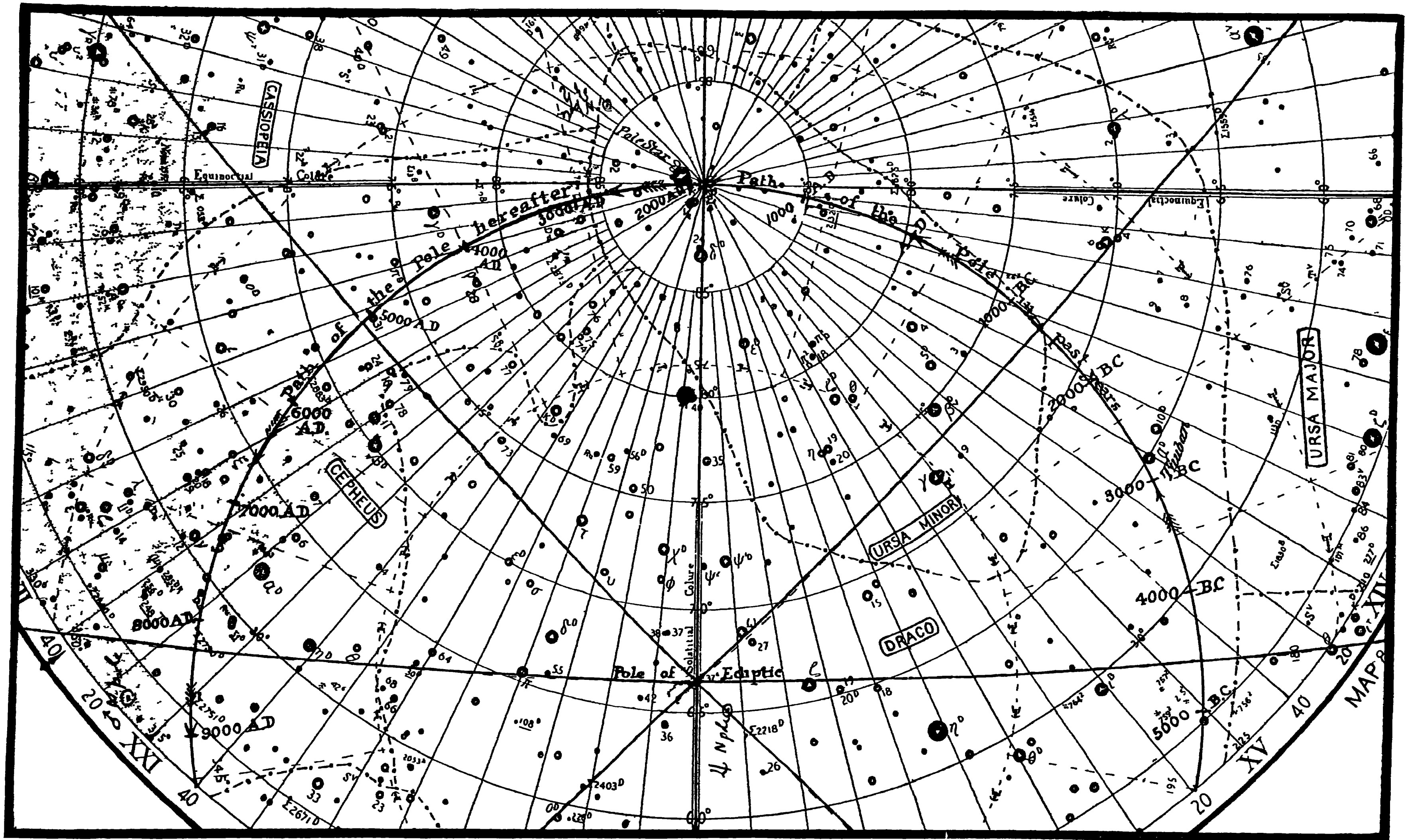
THE ECLIPSE OF MAY 29, 1919, PHOTOGRAPHED AT SOBRAL, BRAZIL

The chief object of the Sobral Expedition was the photography of stars near the Sun, to test Einstein's prediction of light-bending The corona and prominences were also recorded on the plates The great arched prominence on the top left side appeared of a vivid red colour It was 300,000 miles long (farther than from the Moon to the Earth) The V-shaped rif at the bottom appeared very striking



LUNAR, SOLAR, AND COMBINED TIDES.

The Moon is supposed to be New at midnight on the first of the month, Full at midnight on the sixteenth, solar high tide is supposed to be at noon and midnight, lunar high tide gets later three quarters of an hour each day The diagram shows how the combined tide gradually diminishes in size from New to First Quarter, then increases again up to Full. Also from New to Quarter the combined tide precedes the lunar tide or *primes*, from Quarter to Full it follows the lunar tide or *lags* The diagram would serve equally if the Moon were Full on the first, New on the sixteenth.



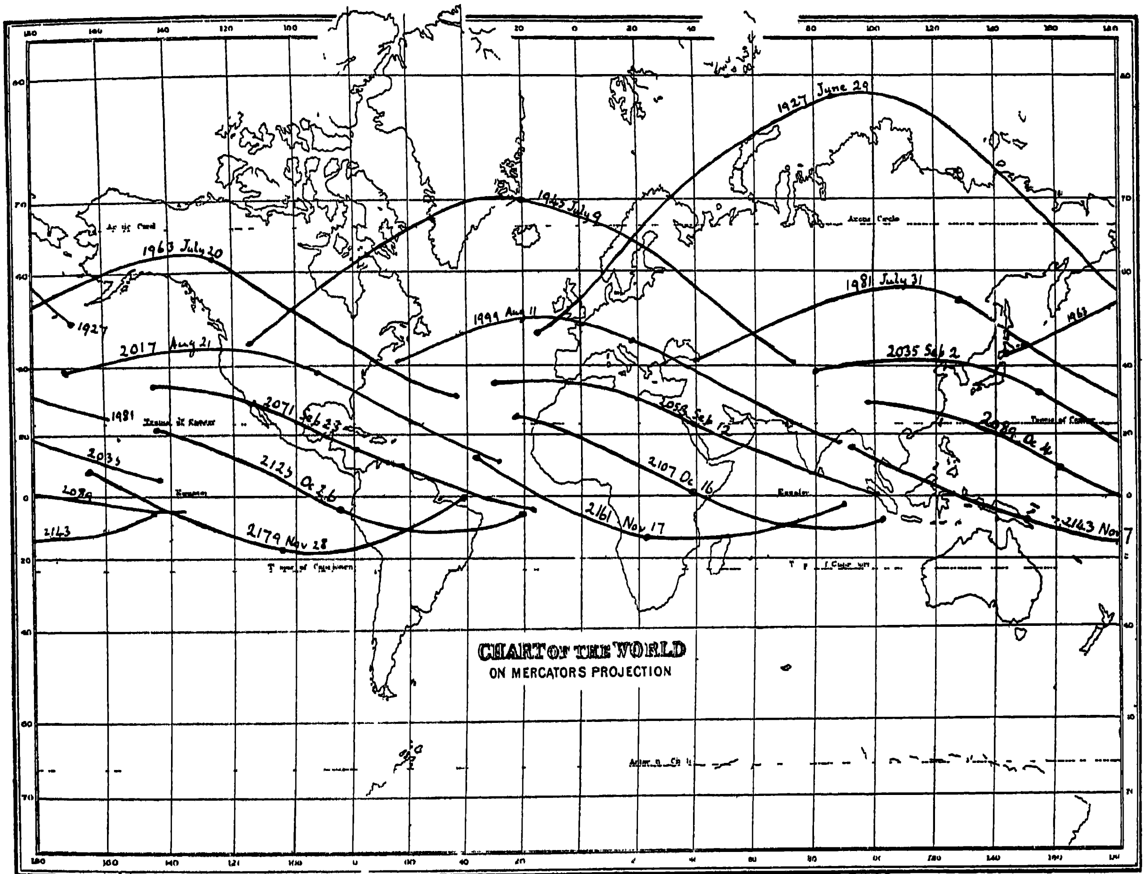
From "Knowledge"] [After R A Proctor

MOTION OF THE NORTH POLE, OWING TO PRECESSION, FROM 5000 B C TO 9000 A D

Precession causes the North Pole to describe a nearly circular course round the Pole of Ecliptic in about 26,000 years At the time of the earliest records, Thuban or Alpha Draconis was the Pole Star Our present Pole Star will be nearest the Pole about 2102 A D, distance 28 minutes The bright star Vega in Lyra will be the Pole Star in 12,000 years The Pole of Ecliptic itself moves a little, owing to planetary action on the Earth's orbit The Moon's north pole is only 1½ degrees distant from Pole of Ecliptic, and circles round it in 18½ years

show it for one fortnight, but the remainder of it consists of simple repetitions of the part drawn, alternately backwards and forwards

We must endeavour to get a more definite idea than hitherto of the exact nature of the Sun's disturbing force We turn to the figure on page 234, noting that the figure is made to serve two different purposes For the present we take C as the Earth, A, B, A′, B′ as the Moon's path round the Earth, M as the Sun, O as any position of the Moon, draw ON perpendicular to MC, and take NH equal to twice NC, join OH Then the reader with an elementary knowledge of dynamics will see that if MO measures the force of M on O, MH will measure on the same scale the force of M on C, and OH will represent the disturbing force of M on O, as affecting its motion round C Carrying out this process for different positions of O, we find that at A, A′ the disturbing forces are AF, A′F′, at B, B′

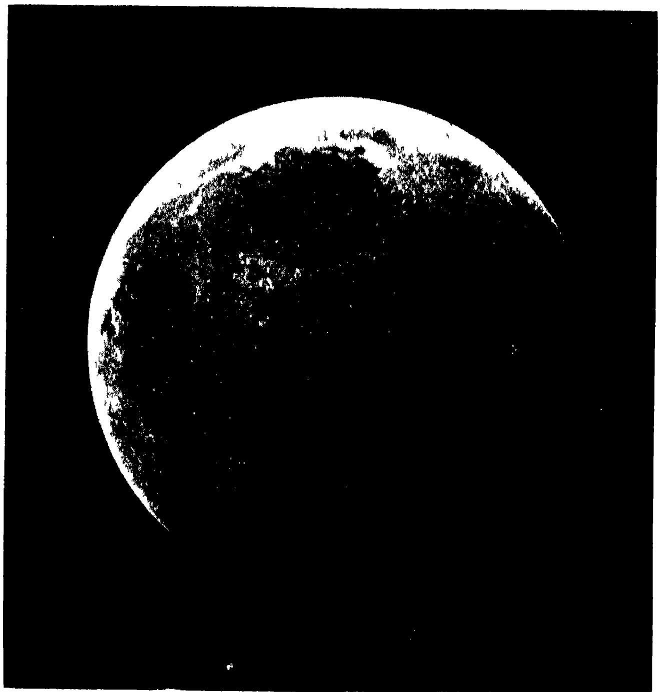


From "Knowledge"] [*A C D Crommelin*

DIAGRAM ILLUSTRATING THE SAROS CYCLE OF ECLIPSES

Eclipses return with closely similar conditions after eighteen years eleven and one third days, the tracks move westward at each return After three returns they reach about the same longitude as at first The tracks of the two English totalities of this century, 1927 and 1999, are shown The cycle continues after 2179, but further data are not available

they are BC, B′C Over the larger part of the orbit the disturbing forces act outwards, they reach their maximum values at New and Full Moon, being then exactly double the inward disturbing force at first and last quarters The result is that on the whole the Sun pulls the Moon outwards, and lengthens its period Now the Sun's distance from the Earth changes by three million miles in the course of the year, being nearest in the winter, the result is that the Moon in winter lags behind her average place, being most behind (one-third of her diameter) about April 1 In the summer, on the other hand, the Sun's outward force is lessened, and the Moon moves quicker, being one-third



Greenwich Observatory] [By permission of the Astronomer Royal

MOON EMERGING FROM TOTAL ECLIPSE

This photograph was taken on November 17, 1910, at 1h 34m a m , twenty-three minutes before the end of eclipse It is possible to deduce from the shape of the shadow that the Earth is round, and much larger than the Moon The rather indefinite border of the shadow is due to penumbra

of its diameter in front of its average place about October 1

At first sight we might expect that the outward force at Full and New Moon would cause the orbit to be lengthened in the direction of the Sun , but this is an erroneous conclusion, as we can see by considering that when the outward force is greatest the greatest outward distance has clearly not been reached , the actual effect is just the reverse, the orbit being flattened at New and Full Moon, lengthened at the Quarters Moreover, the whole orbit is shifted bodily towards the Sun by about 50 miles , the result being that it takes on the average a quarter of an hour longer for the Moon to pass from last quarter to first than from first quarter to last If this difference of times is determined by observation, it gives us a measure of the Sun's distance , it was in this manner that Hansen was able to announce, in the middle of the last century, that the distance, 95 million miles, given by the transits of 1761–1769, was much too great , however, he reduced it too much, giving 91½ million miles, instead of nearly 93 million

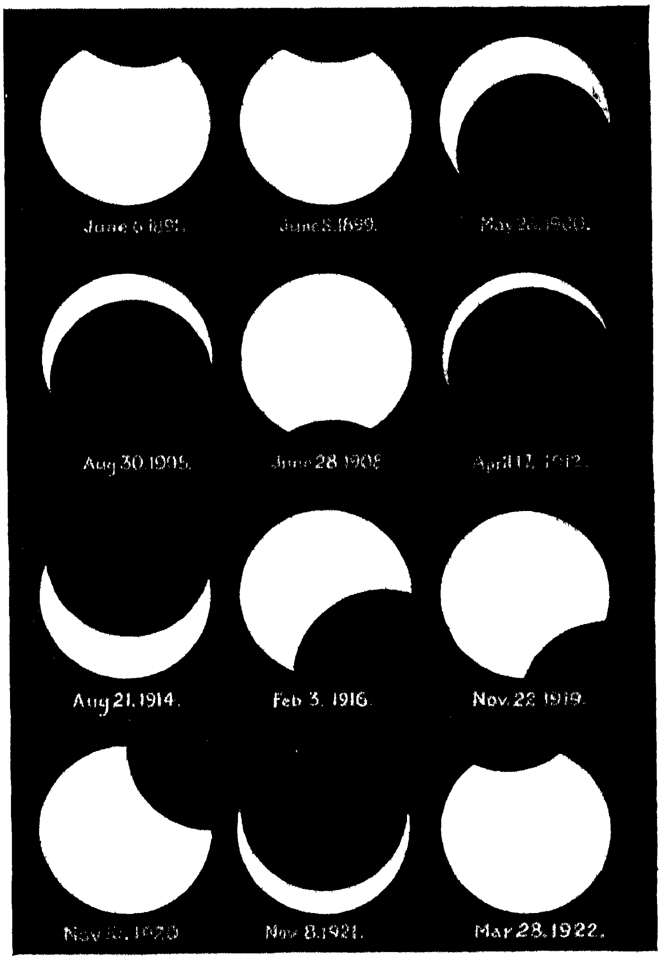
Inspection of the figure, page 234, shows that just after New Moon the disturbing force acts backwards , just before New Moon it acts forwards, the result being that the Moon goes ahead of its average place , it gets farthest ahead midway between A and B, the amount then being thirty-nine and a half minutes of arc, or more than the Moon's diameter , it is an equal distance behind its average place midway between B and A′ , while midway between A′ and B′ it again goes in front, and midway between B′ and A it again lags behind, the amount being the same on each occasion This disturbance of the Moon is known as the Variation It was unknown to the old astronomers, since they trusted largely to eclipses for their knowledge of the Moon's motion, and the disturbance disappears at New and Full Moon It was found some three and a half centuries ago, in the course of Tycho's beautiful series of observations at Uraniborg, which we have already mentioned as giving Kepler the material for establishing his laws

The disturbances that we have hitherto mentioned would take place even if the Moon's undisturbed path round the Earth were circular , but it is, in fact, elliptical, the amount of the eccentricity being one-eighteenth , the meaning of this statement is that the Moon's least distance falls short of the average by one-eighteenth of 239,000 miles or say 13,000 miles , the greatest distance exceeds the average by 13,000 miles Without going into mathematics it is easy to see that the Moon, when farther from the Earth, is far more liable to solar disturbance than when near the Earth The effects have been already noted , they cause the long axis of the orbit to move forward, going right round in eight years ten months , and they cause the eccentricity to increase to one-fifteenth when the long axis points sunward (at these times the Moon's least distance from the Earth is only 221,600 miles) , on the other hand, when the long axis is square to the Sun's direction the eccentricity falls to one-twenty-third

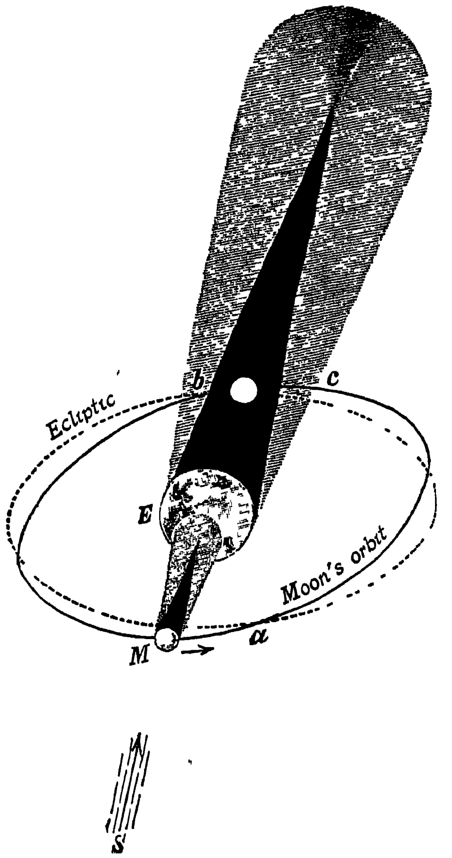
The disturbances just mentioned are grouped as the Evection, their discovery is due to Claudius Ptolemy, the great Egyptian astronomer who flourished in the second century A D, his name is well known as the inventor of the Ptolemaic theory of the planetary motions

We have now gone as far in the study of the Moon's disturbed path as it is possible to do without mathematics The process of calculating a place of the Moon consists in first finding its mean place, which is the place resulting from uniform motion at the average rate, to this have to be applied the effects of the elliptic motion, and of the various disturbances, the chief of these have been described, but there are hundreds of smaller ones Each separate disturbance may be viewed as a wave, which puts the Moon alternately in front and behind its mean place, the figure on page 235 shows the larger waves, the object of lunar tables is to find what portion of each wave we have to use at a given time, the effects of all the waves have to be combined and applied to the mean place, the result gives the actual place, to calculate a single place of the Moon requires over an hour's work, but many short-cuts are possible when one computes the positions for a whole year at a time

Let us now consider what effect these variations in the Moon's motion have upon the face of the Moon that is turned towards us, we have already alluded to the fact that we always see very nearly the same face, owing to the fact that the Moon spins on its axis in exactly the same time that it takes to go round the Earth The spinning motion is very nearly uniform, while we have seen that the motion round the Earth is subject to large disturbances, the result is that when the Moon is ahead of her mean place, a portion of her surface on the west side is brought into view, conversely, when the Moon is behind her mean place, a region is brought into view on the east side of her disc, the words "*east*" and "*west*" are used with reference to our sky, not as they would appear to an observer on the Moon, who would reverse them The swing on each side of the mean place amounts at times to nearly eight degrees There is another cause that brings some of the back of the Moon into view The Moon's north pole is one and a half degrees from the pole of the ecliptic, and moves round it in eighteen and a half years in such a way as always to be inclined some six and three-quarter degrees from uprightness to the level in which it travels round the Earth, the result is that we see alternately an extent of six and three-quarter degrees beyond each pole of the Moon Moreover, the Earth looks so large as seen from the Moon (radius about one degree) that by travelling to different parts of the Earth we can add a zone about a degree wide to the region brought into view On the



SOLAR ECLIPSES VISIBLE IN ENGLAND, 1891–1922
The picture shows, with one exception (1895), all the solar eclipses visible in London in thirty-two years About forty partial solar eclipses are visible at a given station every century, but only one total eclipse in three centuries (on average) In the above illustration Nov 8, 1921, should read Apr 8, 1921



From "Astronomy for All" [*By permission of Messrs Cassell & Co, Ltd*

SLOPE OF MOON'S ORBIT TO THE ECLIPTIC

The Moon's path is inclined five degrees to the Ecliptic The two crossing-points, called the nodes, make a complete circuit in eighteen and a half years in the opposite direction to the arrow

whole we see at one time or another fifty-nine per cent of the Moon's surface, and only forty-one per cent remains permanently hidden But it must be noted that the regions thus brought into view are always near the edge of the Moon, where they are subject to great foreshortenings

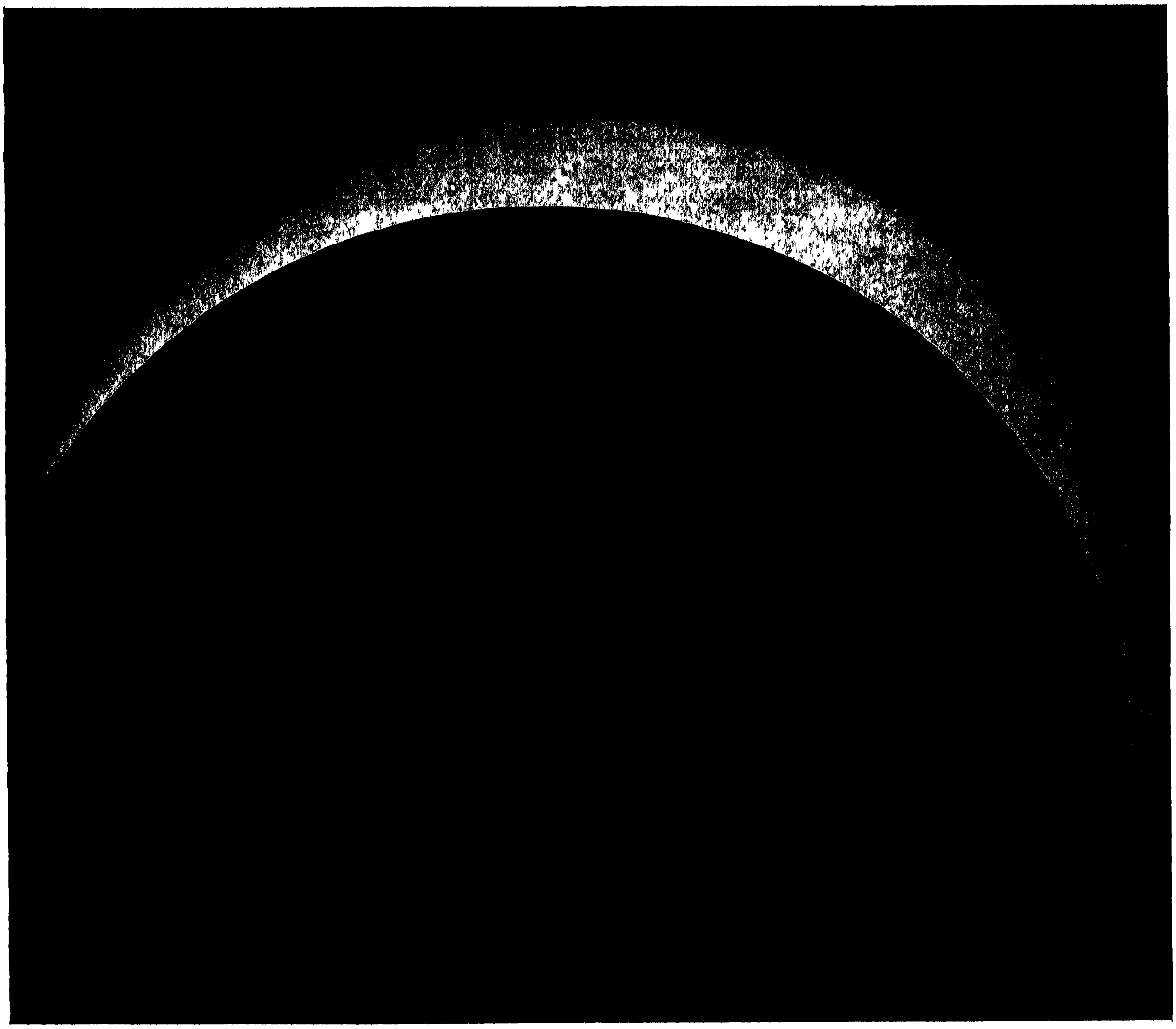
We now proceed to consider the effects of the Moon on the Earth We may divide these into three heads (1) the Earth's monthly journey about the centre of gravity, (2) the Tides, (3) Precession and Nutation

(1) We have spoken up till now about the planets going round the Sun, or satellites going round the planets The expression is a convenient one, but not quite exact, in reality each body goes round the common centre of gravity, if one body is much more massive than the other the centre of gravity is much closer to it In the case of the Earth and Sun the centre of gravity is 278 miles from the Sun's centre, and the Earth makes the Sun describe a little circle with this radius in the course of a year The centre of gravity of the Sun and Jupiter is nearly half a million miles from the Sun's centre, which is just outside its surface, so that Jupiter makes the Sun move quite an appreciable amount In the case of the Earth and Moon, the centre of gravity is 3,000 miles from the Earth's centre, or 1,000 below its surface The Earth then travels round a little circle of 3,000 miles radius in a month, being farther from the Sun by this amount at the time of New Moon and nearer at Full Moon The effect of this motion is to make the Sun appear alternately in front of and behind its mean place by a distance of six and a half seconds of arc Planets that come near the Earth appear shifted still more, in fact, the best way of measuring the Moon's mass is by carefully observing the little planet Eros for several months at a time when it is near the Earth

(2) The Tides are caused by the attractions of the Moon (and also the Sun) not being exactly the same on all portions of the Earth, since both the distance and direction are slightly different for different portions Turning again to the figure on page 234, ABA′B′ now represents the surface of the Earth, C being its centre, and M is either the Moon or Sun By exactly the same reasoning as before, we find that the line OH represents the disturbing force at a point O, also the disturbing force for a considerable distance round the points A,A′ is outwards, while near B,B′ it is inwards, if the Earth were not rotating the effect would be to cause high water at the points A,A′, and low water at B,B′ The rotation of the Earth modifies this result, and actually the line joining the two points of high water does not point to the Moon, but to a point a considerable distance behind, or east of it Indeed, in narrow seas, like those around the British coasts, the time of high water is very much affected by the neighbouring land, and since in any case a full explanation of the tides is impossible without high mathematics, it is usual in elementary works to take the equilibrium theory, giving high water at A,A′ as being sufficiently near to the truth, and also easier to follow We have to note that the Sun raises tides on the Earth, as well as the Moon, indeed, from what we noted as to the superiority of the Sun's pull on the Moon over the Earth's pull, we might expect the Sun's tides to be the larger, but there is a point that comes in here to help the Moon, it is not the whole pull of Moon or Sun on the Earth that is effective in raising tides, but merely the excess of the pull at one

part of the Earth over that at another part, now this is an effect in which proximity gives an additional advantage, so that tidal action varies as the inverse cube of the distance, instead of the inverse square, the Sun is 389 times as remote as the Moon, the cube of 389 is 58 millions, the mass of the Sun exceeds that of the Moon 27 million times, combining these numbers we see that the Moon's tidal action exceeds the Sun's in the ratio of 58 to 27, or $2\frac{1}{8}$ times, it is rather a curious coincidence that this is the same ratio as the excess of the Sun's direct pull on the Moon over the Earth's direct pull

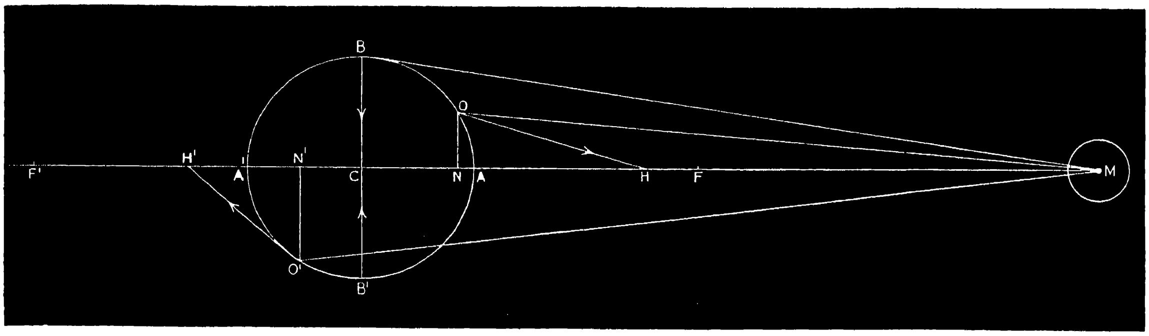
The solar tides are large enough to modify the lunar ones very appreciably, the two tides act together at New and Full Moon, and we then have tides that both rise and fall to a great extent, the solar tides always remain at the same hour of the day, but those of the Moon get later on the average by three-quarters of an hour daily, after New and Full Moon the solar tides precede the lunar ones, and the combined tide is earlier than the lunar one, the tides are then said to "prime", before New and Full Moon the lunar tide precedes the solar one, and the combined tide is later than



From "Knowledge"] [*Photo by E W Barlow*

THE PARTIAL SOLAR ECLIPSE OF APRIL 17, 1912

This photograph was taken at Bournemouth at the greatest phase, 12h 5m p m, one-twelfth of Sun's diameter remaining uneclipsed The eclipse was central some 200 miles to the south east, proving that the Moon's diameter is in round numbers twelve times 200 miles (actual value, 2,160 miles) Some mountain peaks on the Moon's edge are visible one-third of the way from the right cusp to the left one



[A C D Crommelin

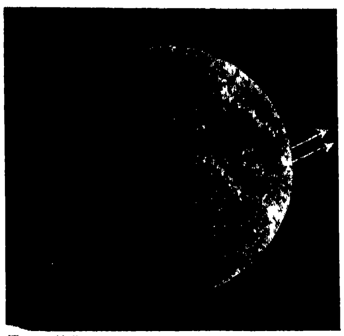
DIAGRAM ILLUSTRATING LUNAR PERTURBATIONS, TIDES, AND PRECESSION

This diagram serves many purposes First, C is taken for the Earth, A B A′ B′ for the path of the Moon, M for the Sun Secondly, A B A′ B′ is the surface of the Earth, and M stands for either Moon or Sun, the second system is used for the explanations of Tides and Precession

the lunar one, the tides are then said to "lag" At first and last quarters high tide from the Moon coincides with low tide of the Sun, the two tend to neutralise each other, and neither rise high nor fall low The total rise at neaps is little more than a third of that at springs

The problem of calculating the tides in advance is very similar to that of calculating the Moon's place, for every variation in the Moon's motion has a counterpart in the tides, there is a further complication in the fact that the tides depend partly on the height of the Moon at the given station However, less accuracy is needed in tide prediction, and as it consists in taking the combination of a large number of separate waves, similar to those on page 227, it is possible to construct machines which give the result for a whole year in the space of an hour or two Machines known as tide-gauges, consisting of floats rising and falling with the water, whose movements are recorded on a revolving drum, permit the various tidal factors to be found for each station, with these, tidal prediction becomes simple

I have already alluded to tidal friction, of whose existence we have a clear proof in the fact of the Moon's rotation having been slowed down to agree with its revolution, we can conclude from the exact accord between the two that the agreement is a permanent one, and that any future increase in the Moon's time of revolution will be accompanied by a corresponding increase in the time of rotation, in order that this may be the case, the Moon cannot be a perfect sphere, but must be somewhat drawn out in the earthward direction, quite a small lengthening (far too small to be detected by observation) would suffice, this lengthening (whose amount has been estimated as 186 feet) gives rise to the "physical librations" of the Moon, whenever, through the various disturbances in the Moon's motion, this long diameter wanders away from the centre of the disc, the Earth endeavours to bring it back, in the case of all disturbances of very long period, such as the secular acceleration, this adjustment acts perfectly, it also acts on the annual term in the Moon's motion, produced by the changing distance of the Sun In fact the largest part of the physical libration has a period of a year, the amount of swing being somewhat over two minutes of arc each way (as seen from the Moon's centre)



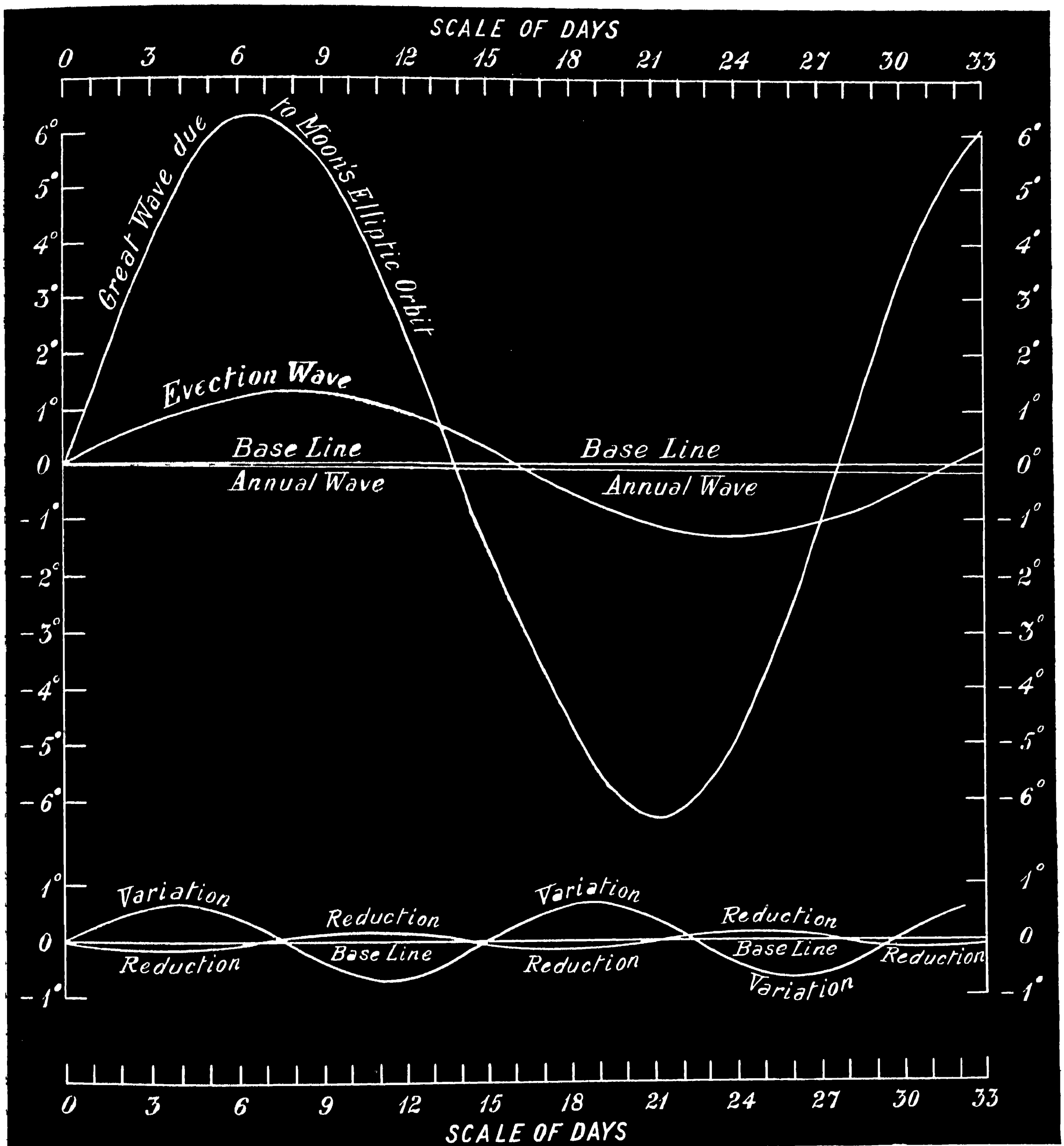
From "Knowledge" [*After Shackleton*

OCCULTATION OF A STAR BY THE MOON

The arrows show the places of disappearance (dark limb) and reappearance (bright limb) as seen from two different stations

It has been found by Messrs Taylor and Jeffreys that the greater part of the tidal friction on the Earth takes place in such partially landlocked seas as the Irish Sea, where the tidal currents are very strong The opening must not be too narrow, thus the Mediterranean and Baltic contribute little, but Behring Sea and the Sea of Japan give a large share, using the best available data about the

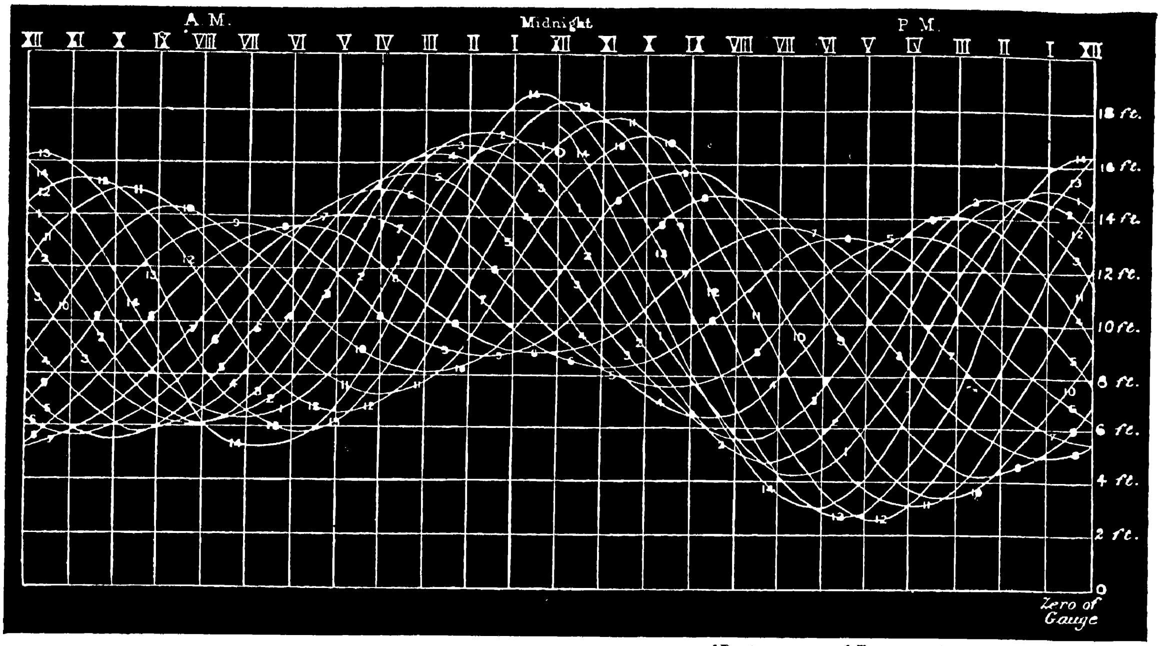
speed of the currents, they found evidence of sufficient friction to explain the apparent acceleration of the Moon of nearly five seconds of arc per century, in addition to the six seconds of arc that is due to the Earth's orbit becoming more circular, which implies a slight diminution in the Sun's disturbing action



[A C D Crommelin.

UNEQUAL MOTION OF THE MOON

The Moon's place is calculated by first taking its motion as uniform, and superposing on the result the heights of a great number of waves, of which the five principal ones are shown above When a wave is below the base line its reading is to be subtracted, when above, added Each wave repeats itself indefinitely, with exact similarity each time, but since their periods are different, each month has a different combination of readings This is the reason of the great complexity in the Moon's motion Practically, it never repeats itself exactly The Elliptic Wave and Evection were known to the ancients Tycho Brahé discovered the Variations and Annual Wave Many hundreds of small waves are included in Brown's *Tables of the Moon*, lately issued, and now used in the Almanacs It is merely for convenience that the above waves are all represented as starting at the same point, actually this seldom or never happens



[*By permission of Encyclopædia Britannica Company*

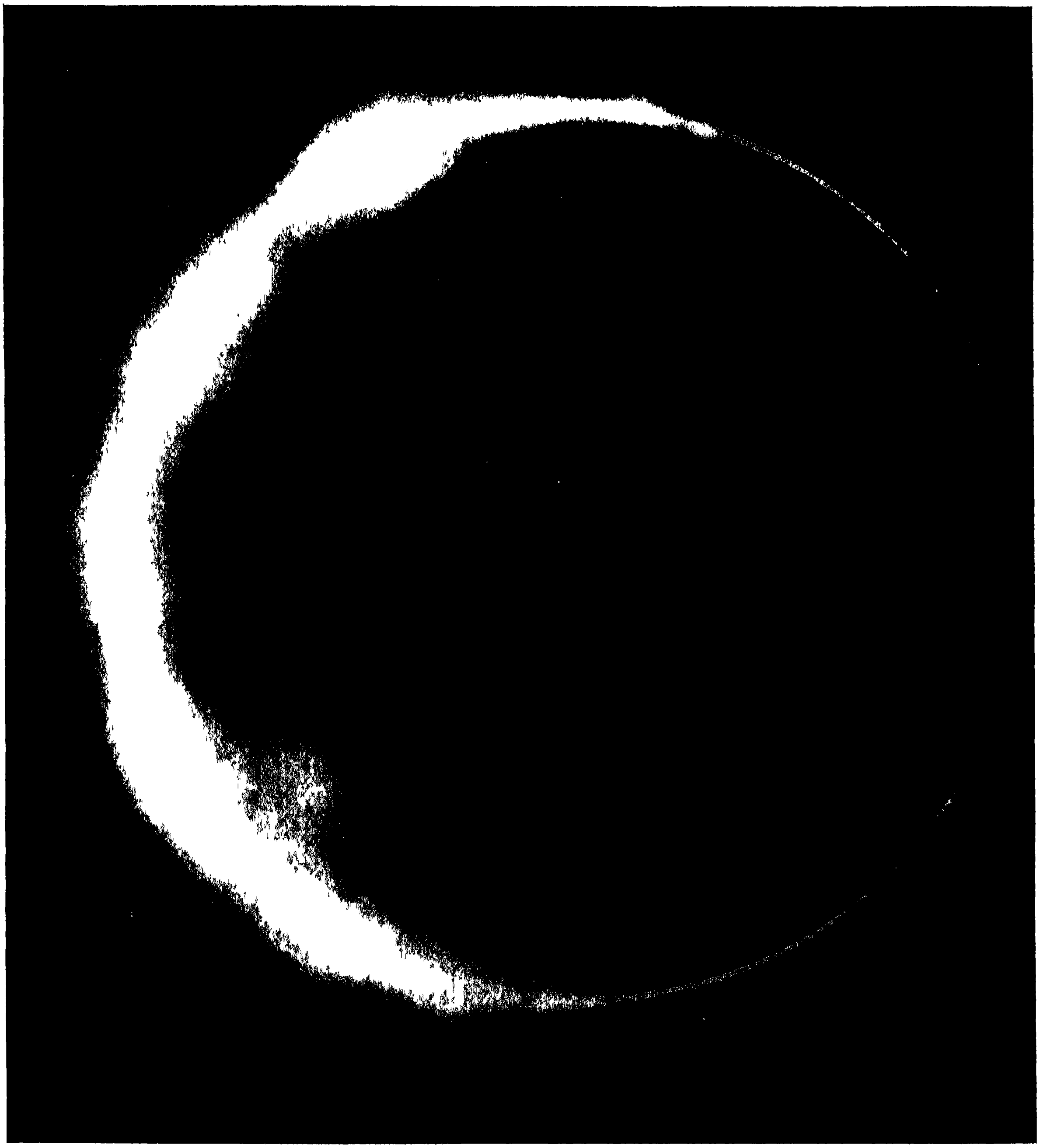
TIDE CURVE RECORDED AT BOMBAY

This curve was automatically recorded at Bombay by a float rising and falling with the tide, and registering on a drum It extends for a fortnight from the beginning of January 1, 1884 The change in the height of high water during the fortnight is shown by the top of the curves, that in the height of low water by the bottom It is clear that the solar high water occurs shortly before noon and midnight The days of the month are written along the curves and help in tracing their succession

(3) Precession and Nutation are effects produced by the Moon and Sun upon the Earth that are in many ways analogous to the tides, but are much slower in their action, while the tides repeat themselves twice in a day, nutation takes eighteen and a half years to run its course, and precession needs a mighty cycle of nearly 26,000 years, they are really two parts of a single action, and the division into two separate titles is made only for convenience

If the Earth were a perfect sphere, an external body would exert no effect whatever upon its rotation or axial pose, one point on the surface being just like another, it would have no purchase anywhere The Earth however differs appreciably from a sphere, the fact of its rotation makes its equator bulge out, the equatorial diameter being 7,925 miles, and the polar one 7,899 miles, so that the former is twenty-six miles in excess For simplicity let us first picture the Earth as a sphere with a single mountain Using the same figure, page 234, that has been used both for lunar perturbations and for tides, let O be the mountain, and M the Moon or Sun Then by just the same reasoning as before, the disturbing force on O is represented by the line OH, that is, it tends to bring O down into the plane of revolution When the mountain is on the reverse side of the Earth, as at O′, the disturbing force is represented by O′H′, that is, it still tends to bring the mountain into the plane of revolution, were the Earth not rotating, the mountain would actually move into the plane of revolution, but the fact of rotation modifies this, and the effect is simply to make O reach the crossing point of the plane a little sooner than it would otherwise do In other words, the crossing point moves backwards, this is quite analogous to the backward motion of the Moon's nodes Now, instead of a single mountain let us imagine a ring of mountains all round the Earth's equator, the action on each mountain would be the same and the backward movement would go on constantly But it is easy to see that a movement of the equator involves a corresponding movement of the north pole, in fact the pole, while it remains practically in the same position throughout any particular year, has a slow reeling movement, exactly like the reeling of a top, like the latter, it takes place in the opposite direction to the spinning

movement, while the spin is completed in twenty-three hours fifty-six minutes, the reel requires almost 26,000 years, so that less than a quarter of it has been completed since the dawn of history A portion of the past and future course of the north pole is given on page 228 It shows that our present pole star will continue to approach the pole for 179 years, being at its least distance (about twenty-eight



From "Knowledge"] *[Photo by MM Demetresco and Croïes*

THE ECLIPSE OF THE SUN, APRIL 17, 1912.

This photograph was taken at Paris Observatory, twelve and a half miles south east of central line The uneclipsed solar crescent, eight seconds of arc wide, appears as a confused glare through over-exposure The bright rim outside the Moon on the right is not the Sun but the chromosphere Several prominences appear, the largest being at the top near the solar crescent Another is just above the Moon's right-hand point The faint glow outside the Moon on the right is probably the inner corona

minutes) in 2102 We are fortunate in having such a bright pole star at the present time, and it is interesting to note that Vega, the brightest star in the northern hemisphere, will be the pole star in about 12,000 years The earliest pole star of which we have historical knowledge is Thuban, or Alpha Draconis, there is no doubt that it was the pole star when the great pyramid was built, the latter has an inclined gallery directed to a point 3° 42′ below the pole, so that we want to find a date when Thuban was at this distance from the pole, the map shows that it was nearest to the pole about 2800 B C, but it was then too near the pole, the two dates when it was at the required distance are 3440 B C and 2160 B C (These were deduced by Proctor, I have verified them within a century) Historical reasons decide against the later date, so the first may be accepted as within a century of the truth, the editors of the *Cambridge Ancient History* assign the date 3100 on historical grounds, but it is pretty clear that it was some three centuries earlier

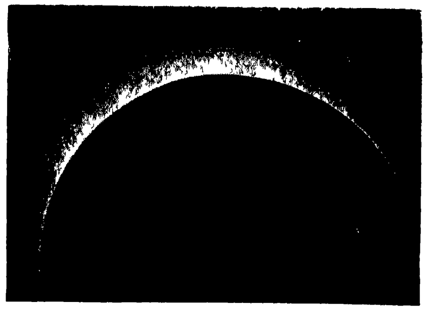


Photo by] [*E W Barlow*
12h 11m G M T
Six minutes after greatest phase, right-hand edge of Sun now visible

The Great Bear was much nearer to the pole in Homer's time than it is now, and he wrote about Mediterranean latitudes, where the pole is lower down than in England Still, his statement that this was the only constellation that never dips in the ocean affords an example of the fact that " Homer sometimes nods "

We see from the map that throughout the first period of Astronomy the pole lay in the Dragon, which thus occupied a position of honour at the top of the celestial dome It is quite probable that the imagery used in the Apocalypse, chap xii, vv 3–9, was suggested by this fall of the Dragon from the position of honour

Of course the south celestial pole moves in a similar manner to the north, it did not, indeed, come within the cognisance of the early observers, still, the records of the stars that they knew enable us to locate the south pole of their times, for there was a circular space left unmapped by them, whose centre was the south pole Both Mr Proctor and Mr Maunder have used this fact for finding the date when the constellations were mapped out, it appears to have been about 2400 B C, or long after the building of the pyramid, but the constellation figures that have come down to us are probably of Asiatic origin, and possibly they repeated some work that the Egyptians had done earlier, or there may have been a revision of an earlier system of figures

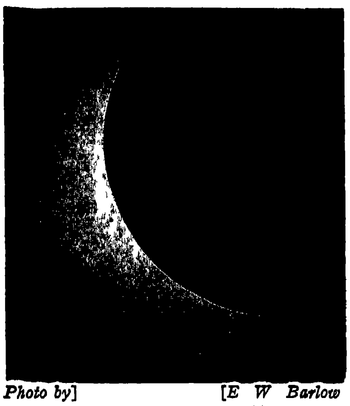


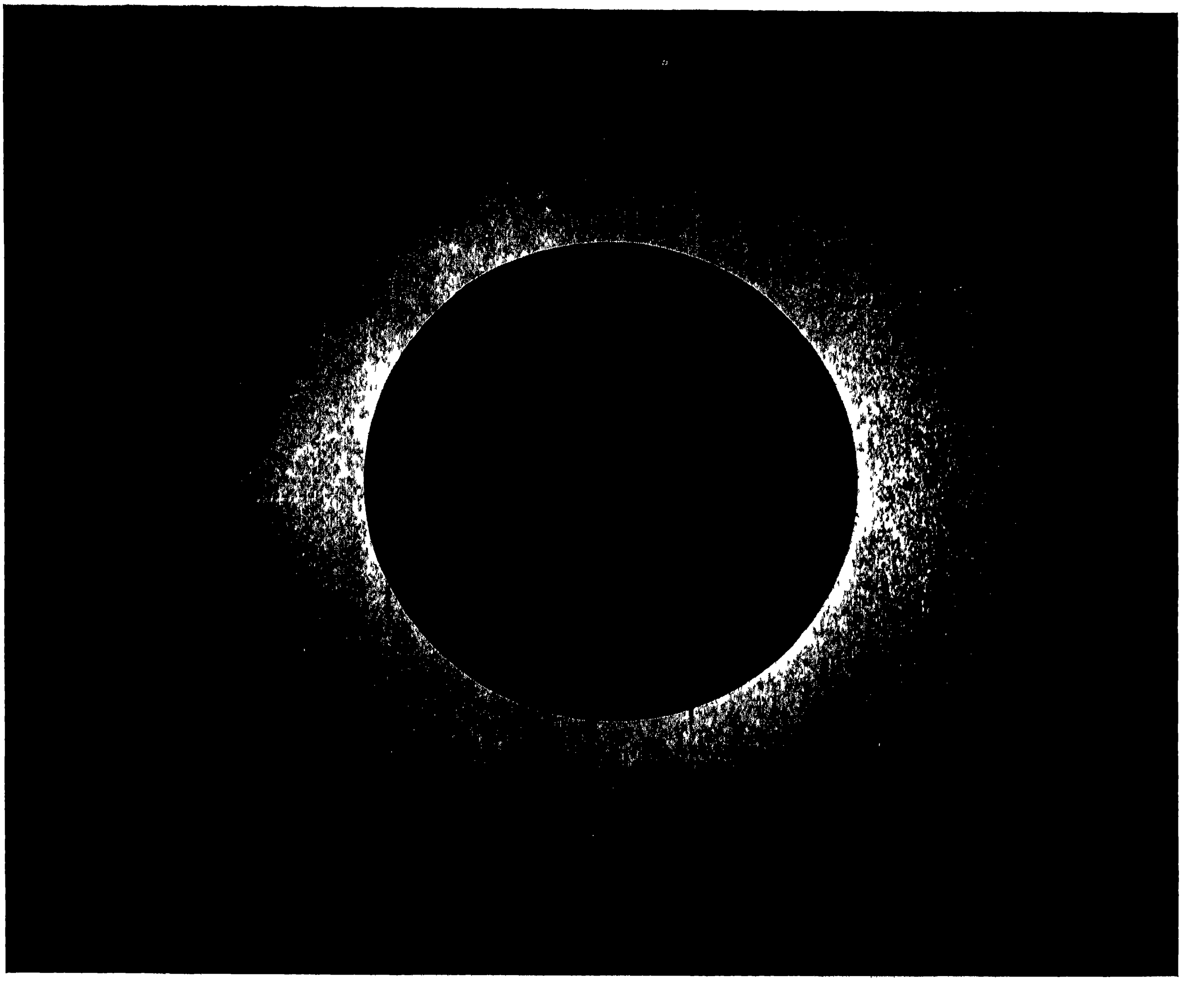
Photo by] [*E W Barlow*
11h 46m 30s G M T
The eclipse is here seen eighteen and a half minutes before greatest phase, two-thirds of Sun's diameter being hidden

We may notice a confusion of names in the constellation Eridanus The name Achernar, which means in Arabic " the last of the river," formerly belonged to Theta Eridani, but was later transferred to the much brighter star Alpha Eridani, which is seventeen degrees farther south This star has been brought farther north by precession, and can now be seen in Egypt, where it was formerly invisible

Precession is divided between the Sun and Moon in just the same proportion as the tides, that is, the lunar action is two and one-sixth times the solar action The action of each body vanishes when it is in the equator, for a body in that position has clearly no power to change the position of the equatorial plane This happens for the Moon once a fortnight, and for the Sun once in six months Hence precession does not go on at a uniform rate, but by jerks, whose size increases with the distance of Sun or Moon from the equator, for convenience precession is looked on as progressing uniformly, and all changes in its rate are collected under another

heading, "Nutation" There is a small lunar nutation with period a fortnight, but a much larger one in a period of eighteen and a half years, in which the Moon's nodes revolve, for we saw that for part of the eighteen and a half years the Moon's orbit is highly inclined to the equator, and the action then goes on more rapidly, but it slows off in the periods of small inclination The solar nutation has a period of six months The word nutation means "nodding," and it is used because through it the pole describes a wavy, serpentine path, instead of a circular one

The planets also play a small part in precession, this is not however by shifting the plane of



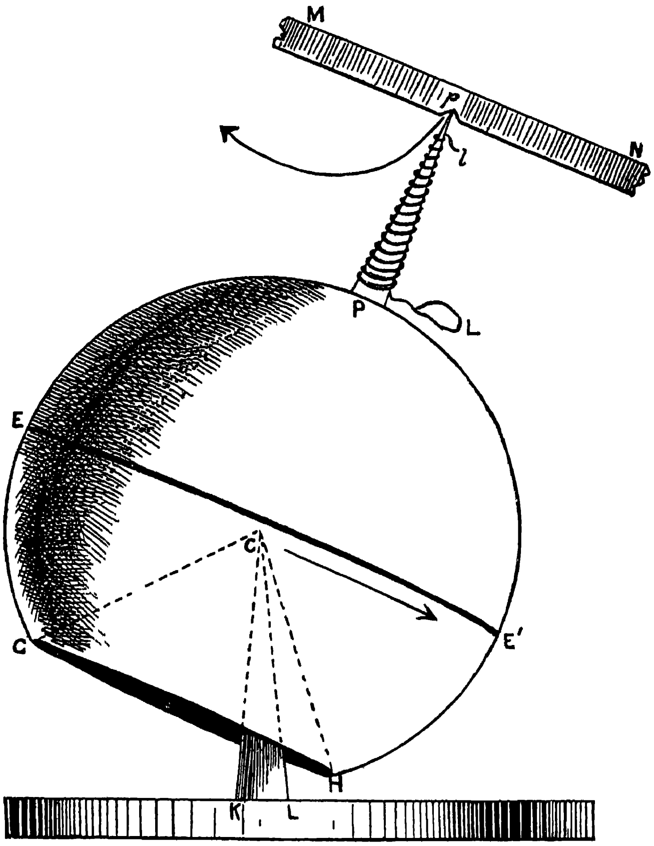
By permission of] [*E N A*

THE TOTAL ECLIPSE OF THE SUN ON SEPTEMBER 21, 1922 PHOTOGRAPHED AT WALLAL, WESTERN AUSTRALIA, BY THE CROCKER ECLIPSE EXPEDITION, WITH A FORTY-FOOT CAMERA AND THIRTY-TWO SECOND EXPOSURE

The Lick Observatory Expedition, under Prof Campbell, succeeded in verifying Einstein's prediction of the deflection of the rays of light from the stars by the Sun's gravitation, they also secured some beautiful photographs of the corona The original negatives show much more detail than we can see in the reproductions

the equator, but by shifting the ecliptic, or plane in which the Earth goes round the Sun, this has an indirect effect by slightly altering the distance of Sun and Moon from the equator

Occultations of stars by the Moon form a very pretty spectacle, and one that our readers may enjoy with quite a small telescope Indeed, if they desire to do really useful work they have only to record the exact times of disappearance of the star, getting their time by the wireless signals that are now so widely distributed. Perhaps the most attractive are those when the Moon is sufficiently



From "Knowledge"] [*After R A Proctor*

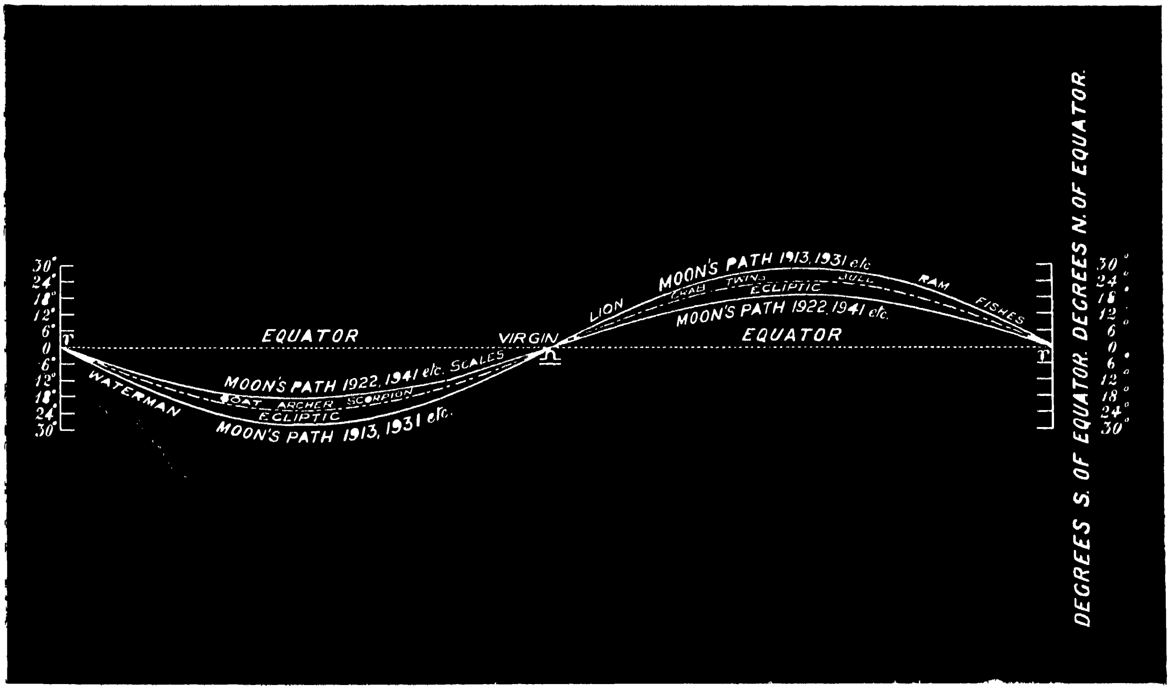
TOP DESIGNED TO SHOW PRECESSION

This top has a conical space cut away, and is made to spin on a spike KCL The lower part of the top should be weighted with lead to balance the part removed MN is a handle held against the axis while starting the top, and then removed The arrows show the directions of spin and of reel

near New to enable the dark part to be seen by earthshine, as one can then watch the approach of the star to the Moon's limb, and see for oneself how rapidly the Moon moves, the disappearance and reappearance take place with startling suddenness, and afford one of the most decisive proofs that the Moon is practically airless As this is a conclusion of great importance it is well to trace out the proof in some detail There are two ways of measuring the diameter of the Moon, the first is by observing the disappearance and reappearance of a large number of stars during a total lunar eclipse, this time is chosen because much fainter stars can then be observed close to the Moon than when it is shining brightly In this way it was found that the Moon's radius, when at its average distance, covers an angle of 15′ 32″ 65 Direct measures of the apparent size of the Moon, made with the transit circle at Greenwich during a period of seventy years, give a value of the radius one and a quarter seconds greater than this value A large part, if not all, the excess can be ascribed to the known causes of diffraction and irradiation, which make all bright objects look somewhat bigger in the telescope than their true dimensions, the highest value that we can ascribe to refraction at the limb of the Moon is about half a second, it is to be noted that refraction would shorten the time during which a star is hidden behind the Moon Now the refraction of the setting Sun on the horizon has been measured and found to be about 2,000″ If we imagine a ray just missing the Earth's surface, and then passing out of the atmosphere again, it would be double this, or 4,000″, it follows then that the refraction at the Moon's limb is at most one-eight-thousandth of that in our atmosphere This means an almost perfect vacuum It has been objected that most occultations are observed at the dark limb of the Moon, and that during the intensely cold lunar night (temperature several hundred degrees below zero) an atmosphere might be frozen which was present in the lunar daytime However, at times stars of the first magnitude, notably Aldebaran, pass behind the Moon, these can be well observed at the Moon's bright limb, and the discussion of these observations shows that even in the lunar daytime no refraction takes place exceeding some two seconds, which still corresponds to a high vacuum The matter is worth this full discussion, since Professor W H Pickering and some other observers have announced in recent years that they detect marked changes in the relative brightness of different regions surrounding certain craters, notably Eratosthenes, which they ascribe to some form of vegetation that runs its course in a lunar month It is perfectly true that this would be the period of vegetation on the Moon, there are practically no annual seasons, the range of the Sun on each side of the lunar equator being only one and a half degrees, about one-fifteenth of the range on Earth, moreover the lunar night a fortnight long, with its intense frost, must act on vegetation

as severely as a long winter The arguments given above appear conclusive against there being a continuous lunar atmosphere dense enough for vegetation, the only suggestion that renders the idea tenable is that there may be local emissions of gas and water vapour round certain craters, due to the survival of a remnant of volcanic activity Before adopting the vegetation hypothesis it would be well to consider the possible explanation due to the continual change of angle of illumination as the Sun travels across the lunar sky, and the fact that different chemical substances have different reflection ratios for a change of angle

It is instructive for us to try to picture the aspect that the heavens would present to an imaginary lunar observer The stars would travel round the sky owing to the Moon's rotation, as they do to us, but far more slowly, requiring twenty-seven and one-third of our days to complete their course The pole about which they turn is distant only one and a half degrees from the pole of the ecliptic (see page 228) The lunar pole goes round this latter pole in eighteen and a half years, whereas our Earth's pole takes 26,000 years Owing to the Moon's annual journey the Sun takes twenty-nine and a half days (two days longer than the stars) to return to the same position It would be below the horizon for half this period The Earth would remain very nearly fixed in the lunar sky, it would, however, swing for a few degrees on each side of its average position, corresponding to the lunar librations that we observe The Earth would show phases which would always be the opposite of the Moon's phase to us, thus when the Moon is new or full to us, the Earth is respectively full or new to the Moon There are two reasons why we see the earthshine best when the Moon is a thin crescent, first, because the Earth is then more nearly full to the Moon, and secondly, because the thin crescent has less power to light up our air than the more fully illuminated Moon, and this atmospheric glare soon overpowers the earthshine The full Earth appears thirteen times as large as the Moon does to



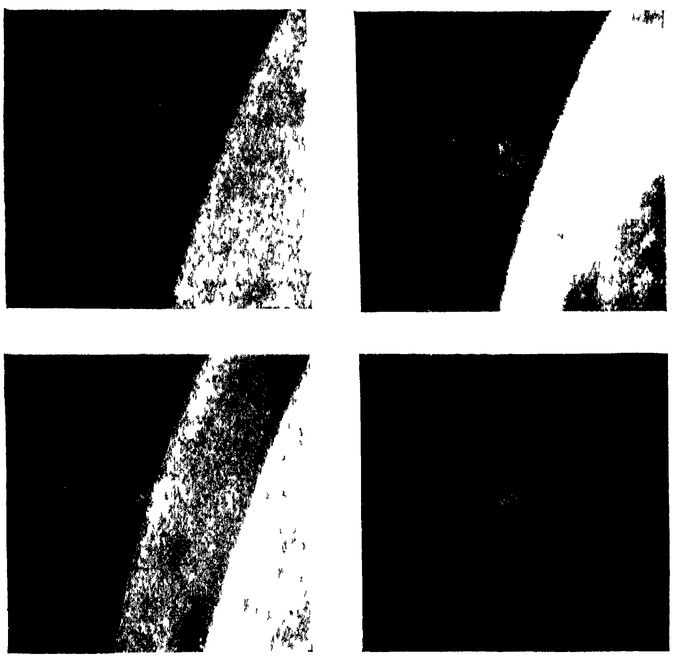
[A C D Crommelin

VARYING SLOPE OF THE MOON'S PATH TO THE EQUATOR

The inclination of the Moon's path to the equator changes regularly in a period of eighteen and a half years It is greatest (over 28½°) in 1913, 1931, etc, it is least (about 18°) in 1922, 1941, etc The Moon's precessional action is much greater in the years of great inclination However, for convenience, precession is considered to be uniform, and the variations in it are put down to nutation Hence the large lunar nutation in eighteen and a half years The points where the ecliptic crosses the equator are denoted by the signs ♈, ♎, which are read as "First Point of Aries," "First Point of Libra" Actually they are now in the constellations of the Fishes and the Virgin

us, and as the albedo of the Earth is higher (see page 108) it would give fully thirty times as much light, it is therefore not surprising that we can see a good deal of detail in the earthlit portion Sir W Herschel saw the bright crater Aristarchus and took it for an active volcano Professor Shaler of Harvard noted that the same regions that look bright at Full Moon also look bright in the earthshine This is important as tending to show that there is no great difference in the state of the lunar surface by day and by night It would be useful to study Eratosthenes in the earthshine to see how the formations appear that Professor W H Pickering describes

A few other points in which the absence of atmosphere would affect the aspect of the heavens from the Moon may be noted There would be no sky illumination, and by simply shading the Sun from one's eyes one could see the faintest stars by day The same applies to the corona and zodiacal light, also there is no twilight, as we can verify for ourselves by noting the extreme sharpness of the boundary between day and night, a mountain peak that has caught the rising Sun shines brilliantly, while the valleys round it are still in darkness



[W H Pickering

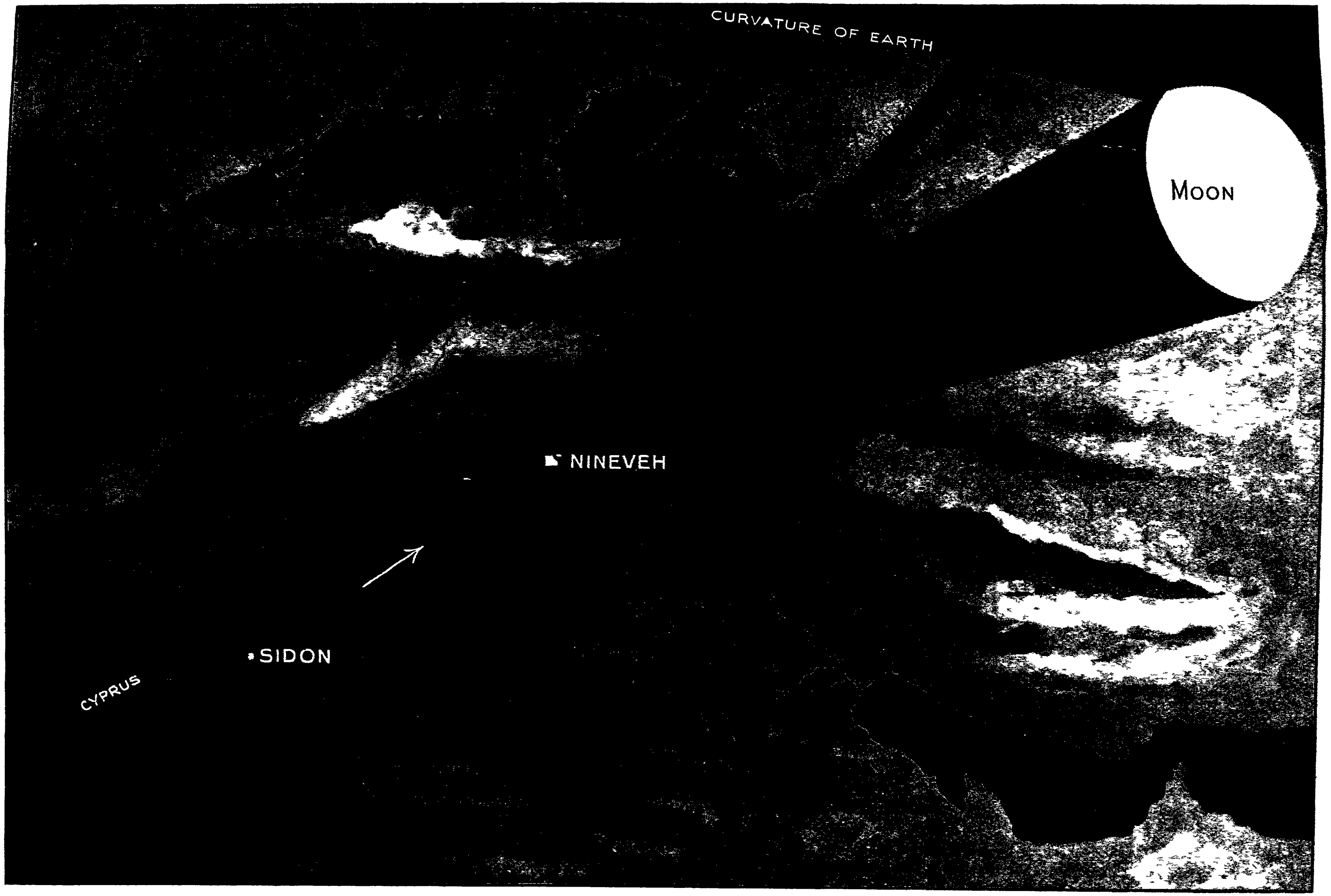
OCCULTATION OF JUPITER BY THE MOON, AUGUST 12, 1892

Jupiter disappeared at the Moon's bright limb and reappeared at the dark one The photographs show no signs of any distortion of Jupiter's disc by lunar atmosphere Jupiter being five times as far from Sun appears fainter than Moon

The planets as seen from the Moon would be in nearly the same positions as from the Earth, the nearer ones would however undergo a small, but quite appreciable shift as the Moon performs its monthly journey round the Earth It may be mentioned that measurement of this shift would enable the lunarians to determine the Sun's distance far more accurately than we can

It is an easy matter to calculate what the amount of the attraction of gravity is at the surface of the Moon, this is a matter that would considerably affect the powers of our imaginary lunarians, and it also has a practical bearing when we come to consider the forces that have moulded the Moon's surface, for a diminution of attraction means that a given amount of force will send a projectile much farther The attraction is directly proportional to the Moon's mass, and inversely proportional to the square of the distance from its centre The distance from centre is three-elevenths of that on Earth, multiplying this by itself and turning the result upside-down we obtain one hundred and twenty-one ninths, we have to divide this by eighty-one, since the Moon's mass is one-eighty-first of the Earth's, we obtain as result that gravity at the Moon's surface is one-sixth of that on Earth This means that if we sprung from the ground with a given speed we should reach a height six times as great on the Moon as on the Earth, and stay six times as long in the air Also a cricket ball flung with the same speed and at the same slope would travel six times as far before reaching the ground Thus if the lunar ring-mountains were formed, as some have thought, by projection of matter from a central volcano, their much larger size than the terrestrial craters would be explained

Another rather surprising result has been deduced from this small gravity on the Moon The Earth's atmosphere, though so dense near the surface, falls off very rapidly in density as we go up,



THE ECLIPSE OF 763 B C, JUNE 15

This eclipse is supposed to be referred to in Amos viii 9 ("sun shall go down at midday") This eclipse is recorded in a cuneiform inscription at Nineveh (see illustration on page 20) Joel ii 31, also uses imagery derived from eclipses ("sun turned into darkness, moon into blood")

From "Astronomy for All"] [*By permission of Messrs Cassell & Co, Ltd*

STEREOSCOPIC VIEWS OF THE MOON

By taking advantage of the Moon's libration, photographs may be obtained giving slightly different aspects On combining these in a stereoscope, the Moon is seen to stand out in relief as a globe

so that our airmen at a height of five or six miles have generally to resort to oxygen to supplement the very thin air At a height of forty or fifty miles the air is so thin that in ordinary language we should be justified in calling it a vacuum However, even this very thin air suffices to cause the shooting stars to glow that are rushing through it at speeds of many miles per second, indeed many of them are completely burnt up and reduced to powder, even at these great heights Now the lesser gravity on the Moon has the effect of making the density of the air diminish much more slowly as we ascend than it does on Earth It has been calculated that assuming the density at the Moon's surface is only 1/10,000 of that on Earth (a quantity that it may quite well exceed) then at a height of some forty-three miles the densities of the two atmospheres would be equal, while if we went still higher that of the Moon would be the denser Thus it turns out that the Moon's atmosphere may form as efficient a screen against meteoric impact as that of the Earth

However, even if this atmospheric screen is present, the dust produced from the meteors would in time settle down on the Moon, now it is clear that the same number of meteors must strike a square mile of the Moon as of the Earth And since we find meteoric dust even in the ooze dredged from the ocean bed the question has been put "How is it that the lunar surface is not uniformly covered with this dust, all variations of tint being obliterated?" The chief difficulty is about several very white regions on the Moon, in particular the crater Aristarchus Since these occur mostly in mountainous regions I make the suggestion that the slope may be too great for the dust to lie, and that it slides down into the valleys The great difference of temperature between day and night on the Moon would cause expansion and contraction, which would help in making loose matter descend to lower levels The so-called "Seas" are the most level regions of the Moon, and their dark colour is quite consistent with the presence of meteoric dust

As a conclusion to this chapter I propose to give in outline the process by which Newton concluded that the force which keeps the Moon circling round the Earth is the same as that which makes an object thrown into the air return to the ground Although the original idea required a genius to discover it, its verification requires no more than simple processes of geometry and arithmetic Simple observations on Earth show that a body dropped from a height falls sixteen feet in the first second Now the Moon is sixty times as far from the Earth's centre as the Earth's surface is, hence the force of gravitation at the Moon's distance, due to the Earth's attraction, should be 1/3,600 of that at the surface (3,600 being the square of sixty) So if we calculate the fall of the Moon to the Earth in a second, and multiply it by 3,600 we should get sixteen feet

Now we get the fall of the Moon in a second by finding how far it is bent away in a second from the line in which it was moving at the beginning of the second Using the figure on page 234, if the Moon be at A at the beginning of the second, and at O at the end of it, AN measures the fall in a second By a proposition in "Euclid," Book III, $ON^2 = AN \cdot NA'$

Now since A is very near O, ON is equal to the arc AO, that is to the circumference of the Moon's orbit divided by the number of seconds in 27 32 days Also NA' is practically twice the

Moon's distance from the Earth or 478,000 miles

$$\text{Thus AN in miles} = \left(\frac{478,000 \times 3\,142}{27\,32 \times 24 \times 3,600}\right)^2 \Big/ 478,000$$

$$\text{AN in feet} = 478,000 \times 5,280 \times \left(\frac{3\,142}{27\,32 \times 24 \times 3,600}\right)^2$$

5 280 being the number of feet in a mile

Working this out (preferably by logarithms), and multiplying the result by 3,600 to reduce to the Earth's surface, we find for the answer 16 1 feet, just the quantity required to prove Newton's Law of Gravitation Newton was for a time kept back through using the wrong radius of the Earth Fortunately he was then able to use Picard's new value, obtained from careful surveying work, and quickly verified his Law

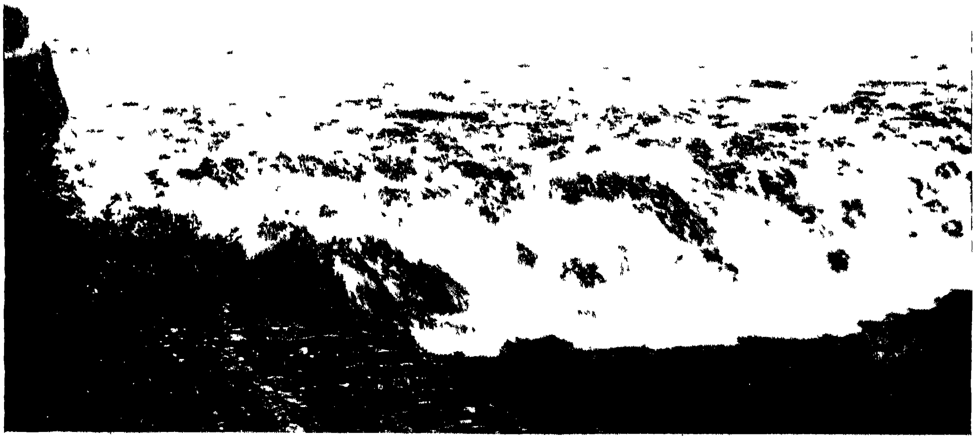
THE CORONA OF JULY 29, 1878

This drawing was made by Prof Langley from the summit of Pike's Peak, 14,100 feet high In that thin air he could trace the corona for eleven million miles from the Sun, a greater distance than any other observer, and saw it for four minutes after the end of totality Sunspot activity was at a minimum in 1878 (see page 112) At such times the coronal extensions are in Sun's equator

THE HISTORY OF THE EARTH-MOON SYSTEM ACCORDING TO THE TIDAL THEORY

By C D Crommelin, B A, F R A S

It has been mentioned in Chapter II that Sir George Darwin suggested that the Moon was a disrupted fragment of the Earth which had assumed its present position owing to the action of tidal friction We are now to enter into this fascinating theory in greater detail It must be stated that Darwin arrived at his ideas by considering the present condition of the Earth and Moon,



THE BORE ON THE RIVER TSIEN-TANG-KIANG, CHINA
In some rivers, owing to contraction of the estuary, the tide rises very abruptly as a great wave, dangerous to navigation The picture helps us to realise the magnitude of the tidal forces

and then working backwards to the period in the distant past when Earth rotated and Moon revolved in the same short time He merely threw out as a suggestion that the Moon was born from the Earth However, this idea is such a natural and simple extension of the picture which he has already adopted as proved, that it seems to belong to the theory

We will therefore start by considering the system as a single body in a molten condition rotating in three to four hours This rapid turning motion set up a strong outward force—known as centrifugal force—which tended to counterbalance gravitation in the regions near the equator Probably this force was not in itself sufficient to enable any part of the Earth to tear itself away from the whole But another cause may have helped it

The solar tides acting on the molten Earth set up in it a vibration with a period of half a day, which in these times was something under two hours Now it may be shown mathematically that the natural or free period of oscillation of a liquid globe of the same materials and density throughout is about one and a half hours The fact that the mass of the Earth is unevenly distributed complicates matters to some extent But when allowances have been made it seems likely that this free period of vibration for the Earth's molten mass was of roughly the same period as the forced oscillation set up by the tides If this was the case the amplitude of the total vibration must have become very large at intervals It is on a similar principle that soldiers are not allowed to cross suspension bridges in step with one another By doing so they would produce vibrations of the same phase and period, which would add together to produce one of very large amplitude In our case at one of the greatest high tides thus produced, equilibrium may have been broken, and a large fragment thrown off

The Earth may thus have passed through the shapes illustrated in Chapter I—from spherical becoming in turn spheroidal, pear-shaped, and finally dividing off in the manner indicated The question arises as to what happened to the larger fragment Did it show no after signs of the tremendous catastrophe? The process, as we have mentioned, probably took place when the Earth was molten It would therefore resume its natural spheroidal shape after a short period But Professor Pickering threw out the tentative suggestion, which cannot be voted altogether impossible, that the cavity of the Pacific Ocean is the remnant of the hollow from which the Moon issued On his view the American Continent was produced by a great landslide towards the chasm An enormous crack was thus formed which is now filled by the Atlantic Ocean

To resume our story The smaller fragment cannot have existed as a single large body at first It must have consisted of an aggregate of particles perhaps arranged in a fashion similar to Saturn's

Rings Some unknown inequality must have made it begin to consolidate on one side of the Earth There is here a gap or weak point in our theory in that it gives no hint as to how the consolidation took place Indeed, as we shall see later, this cannot have been complete until the matter had been pushed out a distance of 11 000 miles or over It is probably more honest to admit that some unknown cause must have assisted both the outward movement and the consolidation

We take up our thread again with a single body, which we can now call the Moon, close to the Earth, revolving round it rapidly, and at the same time rotating on its own axis

At first the Earth's day and the Moon's month must have been of exactly equal length This state of affairs was, however unstable A slight disturbance caused the Moon's speed of revolution to diminish It thus began to cross the Earth's equator from east to west, and tidal friction began to have its play

The Figure on page 249 is a plan of the system we are considering The circle E represents the undistorted Earth, and the ellipse the shape which the tidal action of the Moon has made it assume The arc M_1M_2 is part of the orbit of the Moon, which at this stage was practically circular

Taking the Moon to be at M_2 the Earth would adjust its shape to that of the ellipse shown if there were no friction The effect of the friction is that the distortion does not change quite quickly enough Since the Earth rotates more rapidly than the Moon revolves it carries the distorted shape a little bit in front of the Moon In our diagram this is indicated, for simplicity, by supposing that the Moon has only got to M_1 and the Earth is still the ellipse shown The relative positions of Moon and Earth are occupied with approximate rigidity as the system revolves about O, the centre of the Earth

We thus have to consider how the Moon will act on the unsymmetrical mass shown in the diagram By choosing our masses suitably we can replace the inequalities in the Earth's shape by particles of equal mass at the points P_1, P_2 on the axis of the ellipse The Moon acts on the particles with a force depending directly on the masses, and inversely on the squares of their distances from it As the masses are equal the attraction on that at P_1 is the greater of the two

Now M_1P_1, M_1P_2, the lines of action of these forces, are seen to be on opposite sides of M_1O, the line joining the Moon to the Earth's centre Hence the force

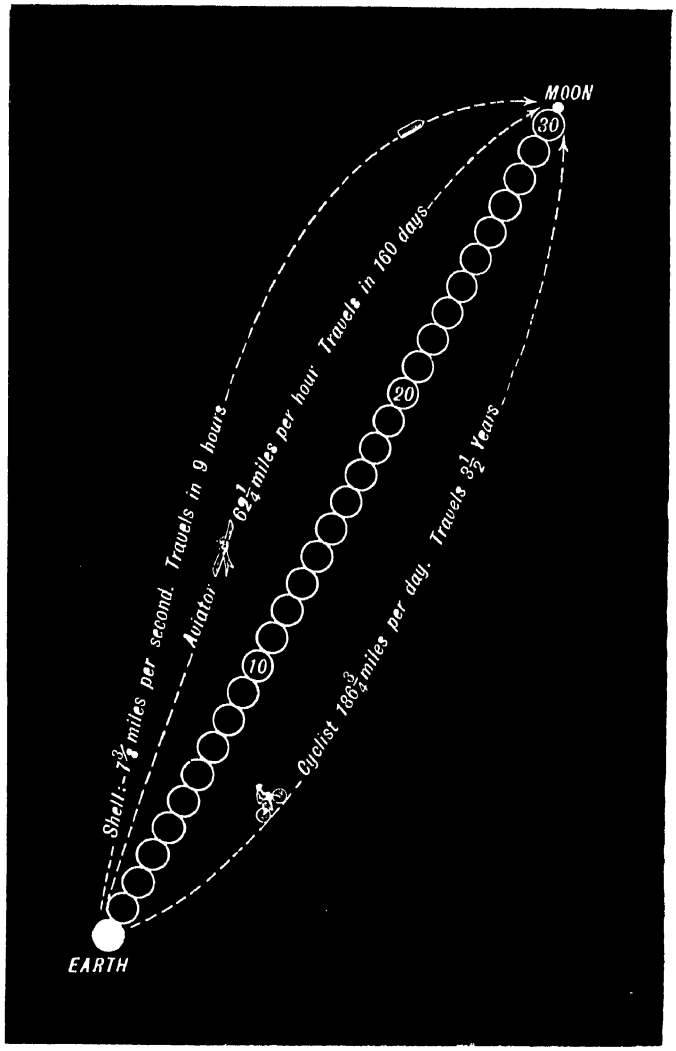


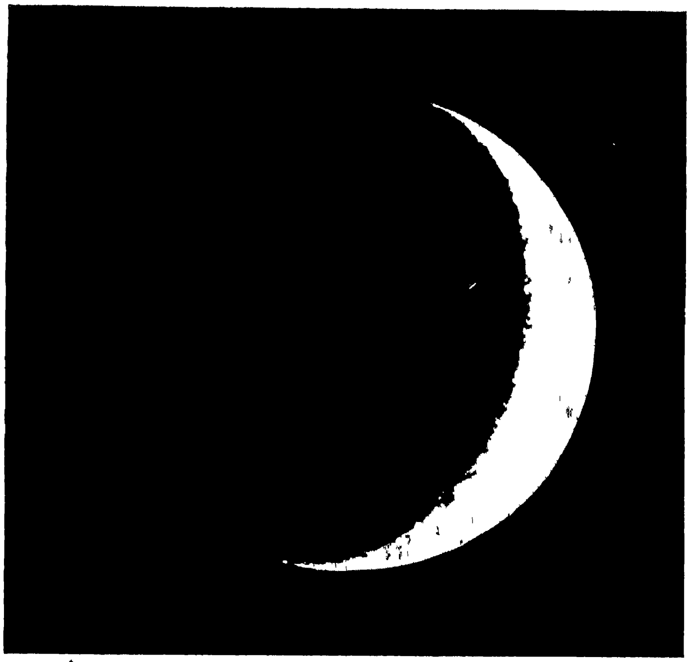
DIAGRAM ILLUSTRATING THE DISTANCE OF THE MOON FROM THE EARTH

The illustration shows thirty Earths spanning the distance to the Moon, and states the times that objects moving at certain speeds would require to reach the Moon (the speed being supposed constant)

at P_1 is hindering the Earth's rotation and that at P_2 is helping it Since the first of these is the greater, the total effect is that the Earth's rotation is slowed down slightly

Again, action and reaction being equal and opposite, the Moon of course is acted on by the particles The force in the direction M_1P_1 is helping its onward motion , that in the direction M_1P_2 is hindering it The total effect is thus, in this case, to increase its speed

Paradoxical as it may seem, the effect of this momentary increase of speed is to push the Moon outwards and eventually to reduce its speed below what it was before When the speed increases the tendency which it has owing to gravity to drop in towards the Earth is lessened It thus moves outwards somewhat in the manner shown in the diagram, page 252 (top) As soon as it has done this the attraction of the Earth ceases to be at right angles to its motion and, instead, acts in a backward direction, thus retarding its speed This final effect overcomes and replaces the original increase of speed—for the direct action of the Earth is far greater than the tidal forces that caused that increase



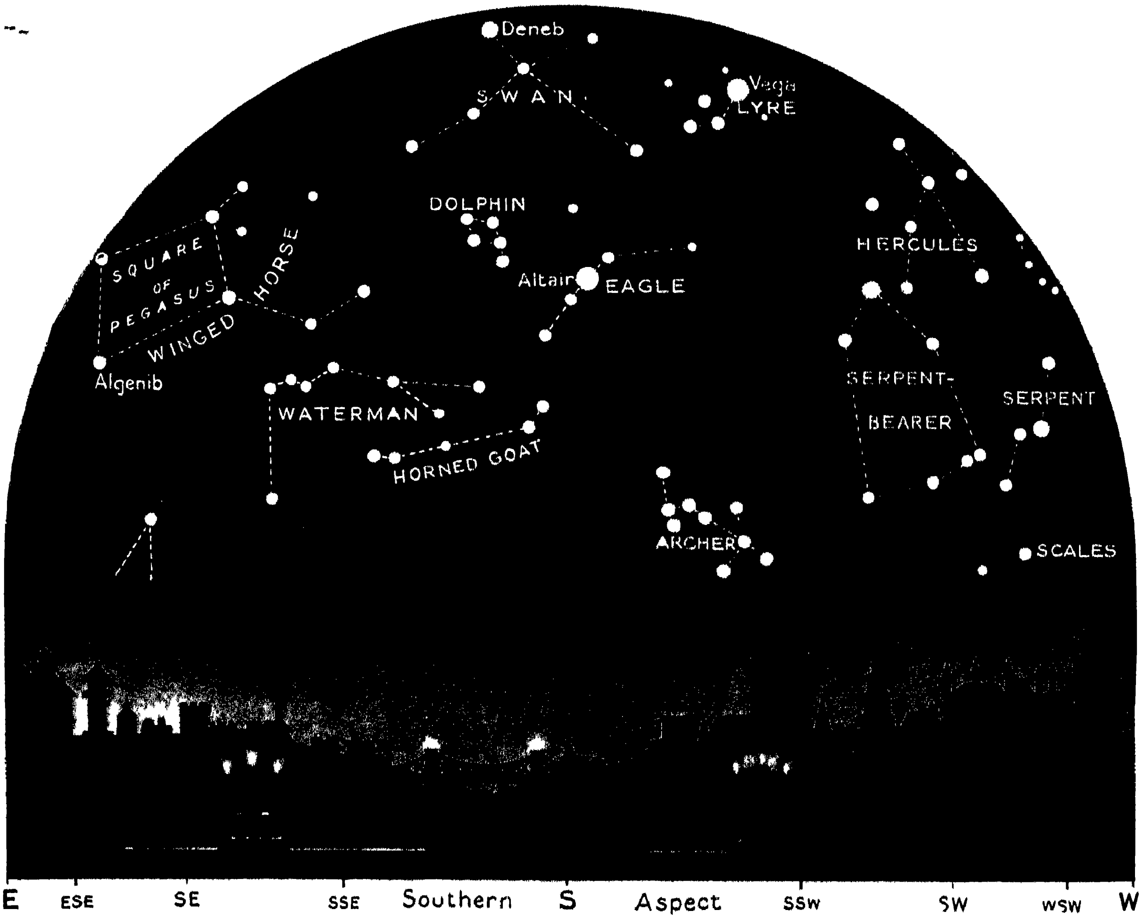
Greenwich Observatory] [By permission of the Astronomer Royal

THE EARTH-SHINE ON THE MOON PHOTOGRAPHED

By giving a prolonged exposure the earth lit portion can be clearly seen and the so called "seas" are faintly indicated The bright crescent is over-exposed and shows no detail This photograph helps us to realise that our Earth is a shining orb

This double process—the slowing down of the Earth and the pushing out of the Moon—once started must, unless disturbed, have continued for countless ages In the early times when Earth and Moon were both fluid and very close to one another the tidal action must have been many times what it is at present Indeed, the efficiency of our slowing down process depends on the distance in a startling manner We have seen that the tide-raising power, and hence the amount of distortion, varies as the inverse cube of the distance of the disturbing body But the actions and reactions that produced the retardation, depending, as they do, on the difference between two nearly equal forces, themselves constitute a tidal effect Their magnitude therefore also varies as the inverse cube of the distance of the Moon from the Earth The total effect must depend on the product of these two factors of change, and thus varies as the inverse sixth power of the distance When the Moon has doubled its distance, its tidal friction efficiency has become scarcely one-sixtieth of what it previously was

The retardation, which was probably rapid at first, thus suffered from its own excesses, and quickly became a very slow process It must be noted that our account has assumed the elementary or equilibrium theory of the tides, for we have taken high water to be under and opposite to the Moon As has already been mentioned in the first section of this chapter, this neglects to take account of the rapid motion of the water in the tides On the dynamical theory the position of high water depends on the depth of the fluid In the case of very deep fluid the high water is still under the Moon In the case of shallow liquid the reverse actually holds, and we get low water in the place of high Present day conditions are so very complicated that none of these theories is in any way complete But in the oceans—away from the interference of land—it has been found that our simple theory is nearest to the facts



THE STARS FOR AUGUST

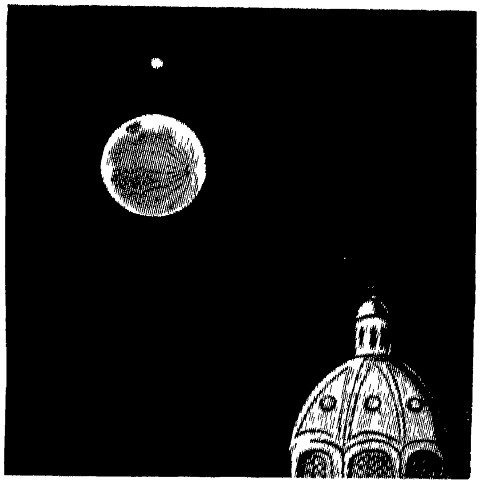
Our plate shows the aspect of the sky as seen, looking North and South, from Westminster Bridge but the positions of the stars will be practically the same for any place in the latitude of Great Britain

The constellations will appear in the positions shown on August 1 at about 11 30 p m (Greenwich Mean Time).
,, 8 ,, 11 0 p m ,, ,, ,,
,, 15 ,, 10 30 p m ,, ,, ,,
,, 22 ,, 10 0 p m ,, ,, ,,

Each night the same aspect is presented four minutes earlier than on the previous night "

However, the phenomena of retardation do not depend on this For it may be shown that the effect of fluid friction in a shallow ocean is to throw the protuberances backwards This case is illustrated in the second Figure, page 252 Here the Moon is at M and the tidal distortions supposed concentrated equally at P_1, P_2 The attracting force in MP_1 is the greater of the two, and this again is hindering the rotation Thus here also we find that the Earth's rotation slows down and consequently the Moon is pushed out

In the early stages, Earth and Moon being fluid throughout—or at all events to a great depth—we see that we were justified in assuming high tides to be under the Moon Our last argument shows that the process would continue in the same manner, though with much reduced energy, even after the planets had solidified It is interesting to note that after the crust formed, the solid Earth continued to have a small tide of its own The extent of this has actually been measured by means of Michelson's interferometer



CONJUNCTION OF MARS AND THE MOON, SEPTEMBER 28, 1909

The Moon in her monthly circuit of the sky necessarily passes near all the planets Some of these conjunctions are closer than others, at times the planet is actually hidden by the Moon

The Moon, we have said, had originally a rapid rotation of its own This also was affected by tidal friction Indeed, since the attracting body, the Earth, is eighty-one times as heavy as the Moon, the retardation was very much more speedy Further, an additional cause was provided tending to separate Earth and Moon

One of the consequences of the theory is that the Moon must once have possessed an atmosphere and great internal heat This may perhaps have been preserved till after its solidification, in which case we can account for the mighty volcanoes which cover its surface

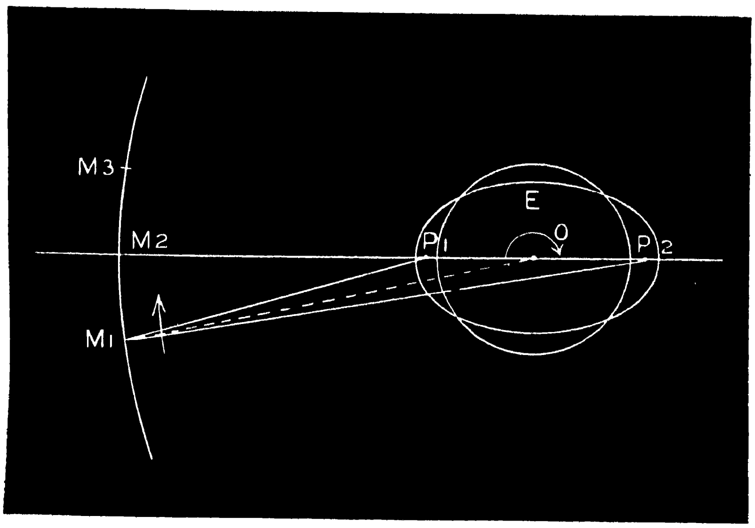


DIAGRAM ILLUSTRATING THE RETARDATION PRODUCED BY TIDAL FRICTION

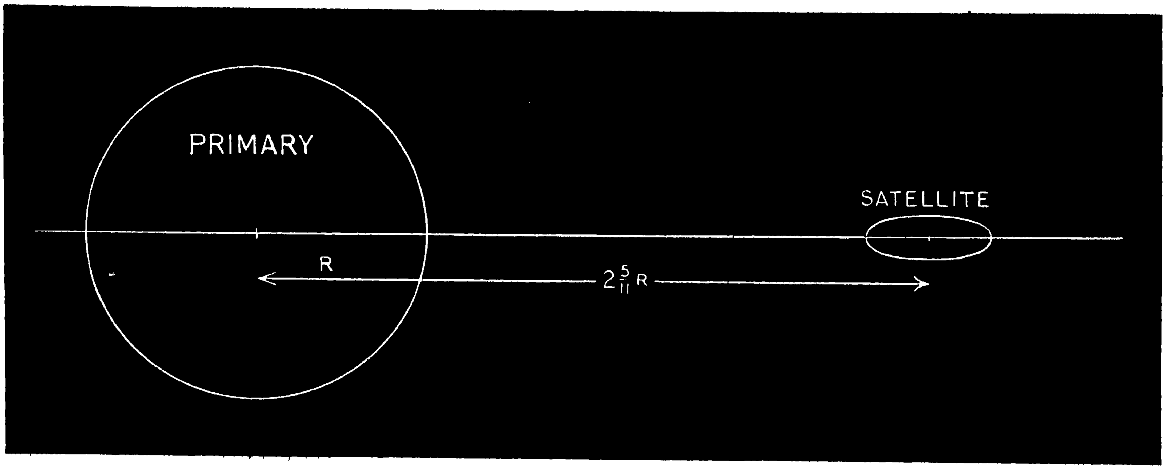
In this figure the high tides are shown under and opposite to the Moon The distorted shape of the Earth's equator is shown by the ellipse The arc M on the left is part of the Moon's orbit Owing to the Earth's rotation the protuberance is carried a little beyond the Moon In this way unequal forces are set up in the lines M_1P_1, M_1P_2, the retarding force, that in M_1P_1, predominates, and the Earth is slowed down

We follow the receding Moon outwards in space through its career of countless ages The month continues to increase, as also does the Earth's day But the former change is more rapid When we began our history the two periods were almost exactly equal As time passed the month became two, three, ten, days, while the day itself changed greatly from its original five hours A crisis arrived when the month became twenty-nine days long Here, calculation shows, the maximum length of the month as compared with the day was reached

Although this state was attained at some nameless age in the past—probably only to be reckoned in tens of millions of years—we see that it is a

comparatively late epoch in the history of the system Afterwards we find the same retarding process going on ever more slowly The month and the day are still lengthening But now the day changes the more quickly The number of days in the month thus begins to diminish

We are gradually brought to our present period, of which the reign of mankind on the Earth is but a brief episode Within the time during which man has made observations of such prominent phenomena as eclipses, the month and the day have suffered no apparent change If change is to be measured, it must of course be shown by a slight alteration in the motions of the stars It might be supposed that ancient observations were too inaccurate for us to base any calculation upon But in the case of eclipses the place of observation, giving the exact position of the shadow cone of a known eclipse, affords that element of precision which would generally be missing The data of the eclipse can be cast back with the greatest accuracy, if we assume the familiar laws of geometry and mechanics In this way the narrow track of totality can be compared with the bare mention of darkness at a given place by some ancient observer As we shall mention later, the work of Cowell



ROCHE'S FIGURE OF A SATELLITE WHEN ABOUT TO BREAK UP UNDER THE TIDAL INFLUENCE OF ITS PRIMARY

In the case illustrated the satellite and the primary are supposed to be of equal density The nearest safe distance separating them is then two and five elevenths of the planet's radius

has seemed to indicate a slight retardation in the Earth's rotation, but the amount of change in the length of the month is almost inconceivably small

The following table will form a useful summing up of the account we have so far given The dates in millions of years should probably be multiplied by five or ten We have no means of determining them absolutely Darwin calculated them by assuming " that tidal friction always operated under the conditions most favourable for rapid change "

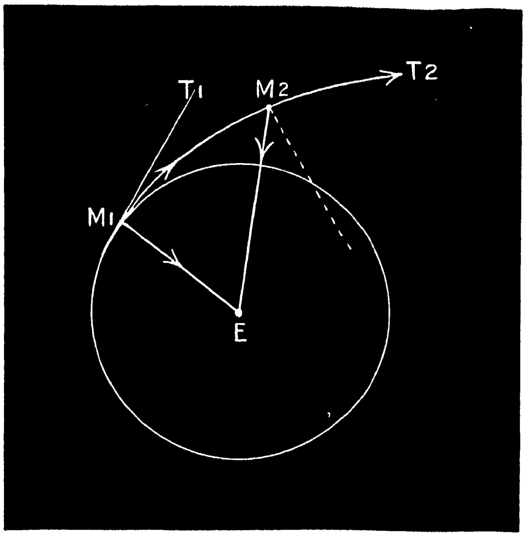
Time in millions of years (dating backwards)	Sidereal day in Mean Solar hours h	Moon's sidereal period in Mean Solar days d	Number of sidereal days in month d	Moon's distance in Earth's mean radii
0 00	23 93	27 32	27 40	60 4
46 30	15 50	18 62	28 83	46 8
56 60	9 92	8 17	19 77	27 0
56 80	7 83	3 59	11 01	15 6
56 81	6 75	1 58	5 62	9 0
—	5 60	0 23	1 00	1 5

It is not strictly accurate to speak of one body travelling round another under gravitation, In reality each travels round the common centre of gravity In the case of the Earth and Moon, the ratio of masses is 81 to 1, and the centre of gravity is three thousand miles from the Earth's centre At Full Moon the Earth is on the sunward side of the centre of gravity, at New Moon on the opposite side This motion causes the Sun to appear six and a half seconds of arc in front of its average place at the Moon's First Quarter, and an equal amount behind it at the Last Quarter

We do not stop here. As the little brook falling down a gentle slope eventually digs for itself a valley many hundreds of feet deep, so do the inexorable laws of tidal friction produce their far vaster effects. Month and day will still lengthen, the latter still doing so the more rapidly. We pass over a gap of time compared with which the history we have already traced must be scarcely more than an hour in a century. And at last we reach an epoch in which day and month are once more equal in length. Each now occupies a period measured by fifty-five of our days.

A strange state of affairs it is. The Moon remains rigid in the heavens. Night and day it hangs over the same spot, shifting but slightly owing to the irregularity of its motion. The Earth's own night must plunge half its surface into the temperature experienced by the Antarctic plateau during its winter.

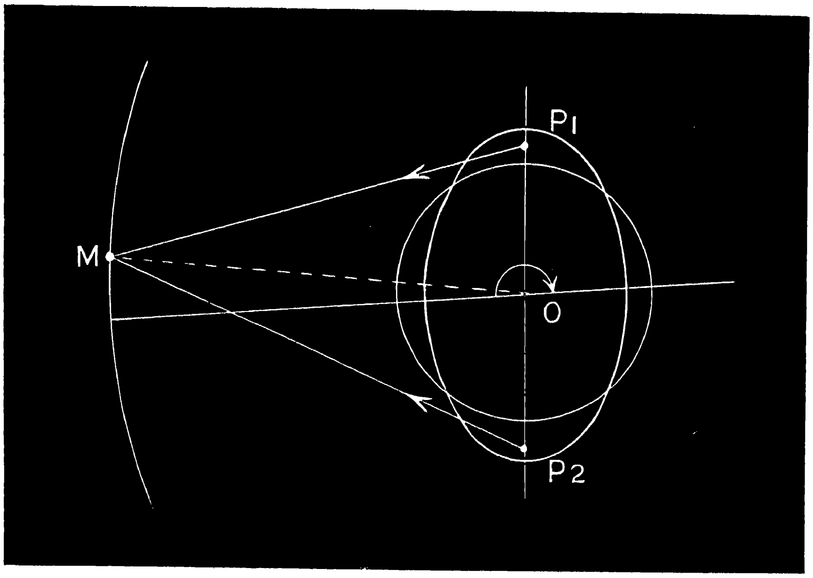
This is the state which the Moon has already, and for a long time, reached. The fact that we can see that it has done so, is a strong corroboration of our theory. The fact would be utterly unaccountable without the assumption of tidal friction.



THE MOON MOVING AWAY FROM THE EARTH

When the Moon's velocity at M_1 is increased, its path approaches more nearly to the direction M_1T_1 of its motion. It thus moves outwards along the track M_1M_2. At M_2 its direction of motion is M_2T_2. The attracting force in the line M_2E is seen to be retarding its speed. As we have mentioned in the text this retardation is the resultant effect.

It might be thought that the great process is at last ended. But this is not the case. The Earth is still rotating slowly relatively to the Sun. The Sun continues to produce its somewhat weaker tides. Tidal friction thus still has its action, and the Earth's rotation is further retarded.



LOW TIDE UNDER THE MOON

This diagram illustrates the case which occurs in a shallow ocean, when low tides are under and opposite to the Moon. Calculation shows that here the effect of tidal friction is to throw the protuberances backwards. The action on the Earth's rotation depends on the difference between the forces in MP_1, MP_2. That in MP_1 being the greater the total effect is again retardation.

A new state of affairs arises. The day is longer than the month. The friction thus causes the protuberance to be left a little behind the Moon. In the diagram on page 249, this can be illustrated by placing the Moon at M_3. It is now seen that the resultant effect is to quicken the Earth's rotation and consequently to bring the Moon inwards.

This effect, though mentioned by Darwin, could only be inconceivably weak. It is a matter of dispute whether in the case of the Earth-Moon system it will take place at all. The slightest disturbance would counterbalance its influence.

This indeed is one of the differences between the first period of rapid motion and this final period—the two epochs of our history in which day and month are equal. The former state was unstable, the slightest disturbing cause being, as we have seen, sufficient to upset it, and to lead without intermission to the most tremendous changes. Unstable equilibrium or steady motion can never last. A pencil balanced on a knife-edge illustrates this point. It will be found impossible to keep it at rest for any length of time. On the other hand, the last dreary state which we have foreseen, is by its nature stable, and small displacements will be followed by a return to the starting point. A familiar example is a ball rolling in a fairly smooth hemispherical bowl.

Wells, in his romance "The Time Machine," has drawn a wonderful picture of the Earth in those far-off days. He has much under-estimated the time required, but his inspiration is entirely drawn from the tidal theory. He imagines the Earth as having reached the stage when it turns one face to the Sun. "The huge red-hot dome of the Sun has come to obscure nearly one-tenth of the heavens." But it gives out little heat. It is very near the Earth, for a resisting medium has drawn the latter inwards.

The scene of the desolate beach with the crab-like creatures crawling about it, of the still, tideless, ocean, and of the tiny flakes falling in the gathering gloom, is irresistibly vivid. We owe no small debt to our theory for having provided the materials for this powerful work of art.

EARTH LIT NEW MOON, FEBRUARY 17, 1907

"The Old Moon in the New Moon's Arms"

As stated in the text, it is possible to see a considerable amount of detail on the Earth lit Moon. The picture, however, somewhat exaggerates the clearness with which it can be seen.

I mentioned that it was in dispute whether the Moon would begin to return to the Earth as soon as the day became longer than the month. There is one case in the Solar System of a satellite taking less time to revolve round its primary than the latter takes to rotate on its axis. This is Phobos, whose month is seven hours, as compared with the Martian day of just over twenty-four hours. Though Phobos is much less massive than the Moon it is also far nearer. A simple calculation, on the basis that the tidal friction effect varies as the inverse sixth power of the distance shows that its power in this process is actually greater than that of the Moon. It therefore seems a certain conclusion that it must be approaching Mars and at the same time increasing its speed. One day it will perhaps fall upon the planet, its final approach being accelerated by the resistance of the latter's atmosphere.

Various other phenomena in the Solar System afford illustrations of parts of our theory. Markings observed on some of the satellites of the giant planets seem to indicate that they turn one face to their primary. The great mass of these planets makes it probable that this would happen.

The case of Venus and Mercury has already been dealt with in Chapter II. If the suggestion that Mercury is an escaped satellite of Venus is sound, there is further valuable confirmation of our theory. The solar tides, unaided by a satellite, should not have been sufficient to slow down Venus's rotation to the condition apparently observed. But the mutual action of planet and satellite would have had a powerful retarding power on each

We have now to mention an interesting kindred effect which is illustrated, so far as we know, by only one body—or rather aggregate of bodies—in the universe, namely, Saturn's Rings These will be described in detail in the Chapter on Saturn Here, we are simply concerned with the fact that they are not single annular forms held rigidly together above the equator Clerk-Maxwell showed conclusively that they must consist of multitudes of small particles revolving about the primary with speeds depending on their distances from it

The tidal theory provides a plausible explanation of the existence of these strange objects For clearness, we will imagine a large satellite being brought closer and closer to its primary We say large, because in this case the forces of cohesion—that is the resistances which rocks offer when we try to pull them asunder—become negligible compared with the mutual gravitation of its particles The shape is thus practically spherical—or rather, spheroidal As the body approaches its primary, the tidal forces become greater and greater, and the form which it is made to assume by rotation becomes more and more elongated Professor Roche has shown that if this elongation becomes too great, instability will set in, and the satellite break into small fragments

CYRANO DE BERGERAC'S FLIGHT TO THE MOON

(*From an old engraving*)

One of the many imaginary flights to the Moon that occur in romances The writer forgot that our atmosphere extends for only a few miles above the Earth's surface The artist has drawn the Moon Full, though near the Sun

As a matter of fact, it is improbable that Saturn's Rings have ever existed as a single large body But obviously the forces that would have broken it up, had it been there, are acting as an effectual check against it forming As we mentioned in the case of the Moon, it is a little difficult to see how it could even begin to consolidate Some external disturbance might tend to make the particles collect on one side In this manner the effects of tidal retardation might set in and it might be pushed outside the danger zone

The least distance at which a satellite can safely revolve round its primary is known as Roche's Limit It depends on the relative densities of the pair If they have the same density the satellite cannot exist closer to the planet's centre than two and five-elevenths of the latter's radius The denser the satellite the nearer it can safely go This is as we should expect, for the attraction that its particles exert on one another becomes relatively greater In the case of the Moon, which is less compact than the Earth, the critical distance is 2 87 Earth's radii, or about 11,000 miles

Phobos actually revolves at a distance of only 2 75 radii from the centre of Mars Apparently, therefore, it is in dangerous circumstances However, it has carelessly been assumed that it is of a sufficiently large size for the forces of cohesion to be neglected Dr Fountain has lately worked out, that assuming Phobos's rock had the consistency of brick, it could come down to Mars's surface without being broken up This, indeed, is a natural conclusion, for it is of the same order of size as some of our great mountain chains These, fortunately for us, show no signs of wanting to tumble over In this connection again it seems probable that some of the minor planets are of irregular shapes Allowing this, we can explain their puzzling changes of brightness in different parts of their orbits

There remains to be considered some of the minor effects that the tidal theory must have had on the development of Earth and Moon. It has been objected that since the present figure of the Earth is very well adapted to its speed of rotation, *i.e.*, that the bulge at the equator is of the amount required to put no strain on the Earth, it cannot have slowed down to any appreciable extent since it became solid. It is true that the Earth is for ordinary purposes more rigid than steel. But Darwin considered that in the case of the enormous centrifugal strains which its rotation produced, it became plastic, and continued to adjust itself to the right shape, as though it were a fluid.

Geology affords no positive support to the theory, unless we accept Pickering's bold guess that the monsters of the Mesozoic Age were enabled to move about freely because at the equator the powerful centrifugal force counterbalanced a good deal of the gravitational attraction. But, on more definite evidence, it is significant that the geologists can bring no logical arguments against the hypothesis.

The following astronomical facts have now to be considered: (1) that the Moon's orbit is not circular, but elliptic; (2) that its plane of motion is inclined to the ecliptic; and (3) that the Earth's equator is oblique to the Moon's orbit. Each of these has interesting side effects on our theory. Taking (1) first, we find that the effect of tidal friction is to change the degree of eccentricity. We have seen that tidal reaction tends to increase the Moon's distance from the Earth. Now this reaction is strongest when the Moon is nearest to us. The effect at this closest point, the perigee, is thus greater than at apogee, the farthest point. The first effect tends to increase the greatest distance, the second, the least distance. And as the first effect is the greater, the orbit expands, at the same time becoming more elliptic. Calculation shows that originally it must have been nearly circular.

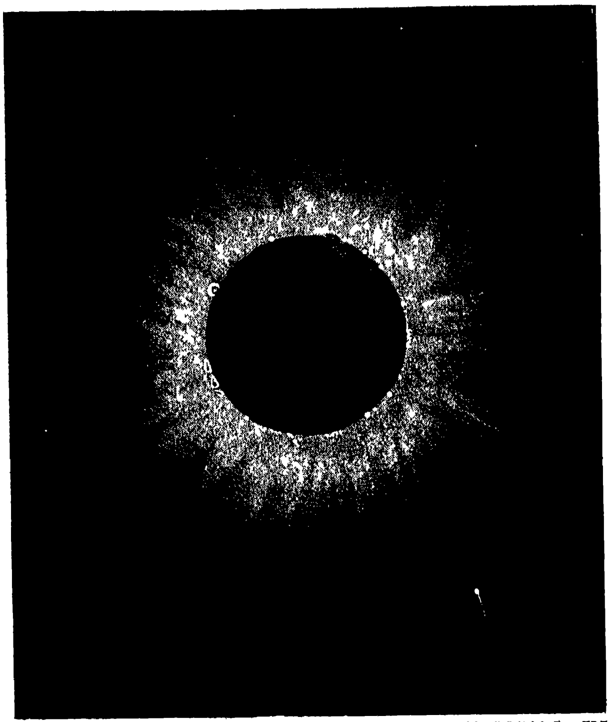
[*From Picart's "Cérémonies et Coutumes religieuses," 1723*

FULL MOON CEREMONIES AMONG THE KAFFIRS

As in ancient times so still among savage peoples, celestial phenomena are regarded with much superstitious awe. Kaffirs and Bushmen celebrate the New and Full Moon with peculiar ceremonies and important tribal assemblies.

The effect of (2) may have some bearing on cosmogony. It is found to depend in a remarkable manner on the number of days in the month. At present and for a long time past it has caused the obliquity of the ecliptic to increase. (Of course we are leaving out of account the calculable periodic effect of the planets upon the obliquity.) But on going back to the time when the day was six and the month twelve of our present hours, we find that this tendency has ceased. In other words, if there are more than two days in a month the obliquity will increase, if less than two it will diminish.

The rate of increase or decrease depends directly on the amount of obliquity at the time concerned. If then a planet such as Jupiter be spinning about a line exactly perpendicular to the plane of its



THE ECLIPSED SUN, PHOTOGRAPHED AT SOHAG, IN EGYPT, MAY 17, 1882

This is the characteristic form of corona near sunspot maximum, the coronal streamers being distributed equally all round the disc The little comet that appears on the plate was never seen again A comet was also photographed in the eclipse of April 16, 1893

orbit, there is no tendency for this state to change We cannot, by this means, explain the whole twenty-three and a half degrees of our present obliquity Calculation shows that when the month was two days long the obliquity was still eleven degrees Moreover, it is impossible to explain the considerable obliquities of some of the other planets to their orbital planes We must therefore admit the action of some unknown cause which started the planets in oblique positions

The third fact, namely, that the Moon moves in an orbit inclined to the equator, produces effects too complicated for us to describe in detail As we have seen, the Moon started to revolve in the plane of the equator The effect of tidal friction has been to make its plane of motion approach the ecliptic At the present time it is inclined to the latter at the small angle of five degrees

It was mentioned that there were no signs of retardation in the Earth's rotation during historical times Recently, however, two indications of this have been found

In the first place it has been found necessary to postulate an apparent acceleration in the Moon's motion This is of course due to a retardation of the Earth's speed of rotation Against it, we have to remember that the month is also lengthening, but this is happening much more slowly, so that the net result is the acceleration observed

In the second place, observation has shown that Mars's rotation is, if anything, quickening Now there are no seas on Mars, so that, though it is subject to the relatively powerful tidal accelerating power due to Phobos, this can merely act on the slight "land" tide and is probably small It seems then possible that the apparent increase of speed is partially due to the fact that the Earth's rotation, our usual standard, is slowing down

It has perhaps seemed strange that on these slight observed data—and indeed without them, for they are recent discoveries—such an elaborate history as ours should have been possible

However, to take a familiar example, we may note that we know the succession of stations between London and Edinburgh, even though we have no time-table Indeed, this is the type of chronology that science provides In geology we cannot reckon the advent of, say, the Cainozoic epoch even in round millions of years But we can give an exact list of the order of formations and organisms from the dim and distant days of trilobites to the arrival of man

We have to sum up the place of our theory as a part of the world's knowledge I do not approve of excessive philosophising upon its conclusions To argue about the inexorable rigidity and sureness of Nature's processes seems to me futile We cannot foresee what sudden external force might upset the whole tenuous structure which we have built up

The theory is a typical piece of science We owe it a debt partially for the food it gives to the imagination, and yet more for the logical symmetry and beauty of the final product Whether it turns out to be true or false, it will remain a fine example of the power of man's intellect in passing over the barriers of space and time

CHAPTER VI

THE MOON

BY WALTER GOODACRE, F R A S , *President British Astronomical Association*

MATTERS relating to the position of the Moon in the Solar System, and its motions in space in relation to the Sun and Earth, having been described in the previous chapter, there remains now the task of describing what we find on its surface, or in other words, the physical features as revealed by the telescope

The overwhelming prominence held by the Moon in the night sky, and its rapid motion amongst the stars in its monthly revolution round the Earth, cannot have failed to impress mankind from the earliest times with its comparative nearness It is indeed by far the nearest of all celestial objects, and the only planet—with the exception of Mars—of which we see the actual solid surface

Up to the year 1609 there was no definite or certain knowledge of the actual physical condition of the Moon's surface, but there were a number of speculations about it One was, that the Moon acted as a mirror, reflecting the features of our own globe, though a moment's consideration would have shown this to be untenable from the fact that the features of the Moon are fixed in relation to each other, whereas the markings should have moved across its face, as the Earth revolved on its axis Another theory suggested that the dark markings on the Moon were opaque bodies suspended in the sky between us and it

The invention of the telescope, and its application to Astronomy by Galileo in the year 1609, at once put an end to all doubt and speculation, by showing to the astonished observers that whilst the Moon was in no sense a replica of the Earth, inasmuch as it possessed no large bodies of water, and no clouded atmosphere, yet it presented some features of similarity—the vast plains (which were mistaken for oceans), and the great mountain ranges, which diversify its surface

No sooner had the telescopes of Galileo's day—poor and imperfect instruments though they were—been brought to bear upon the Moon, than the observers naturally began to make charts or drawings of the principal features they saw, and this laid the

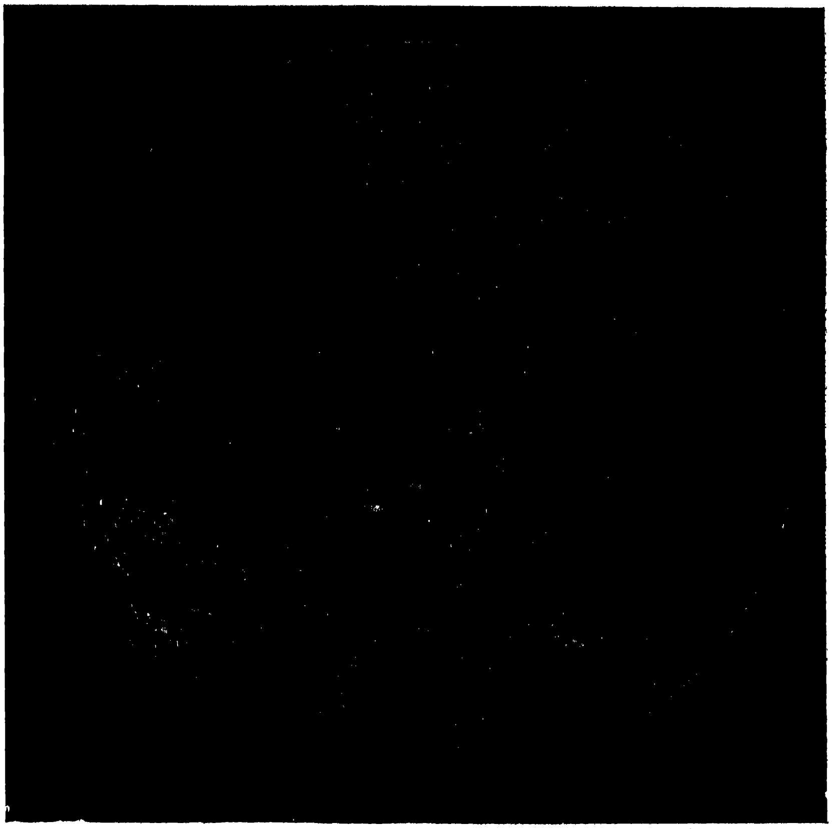
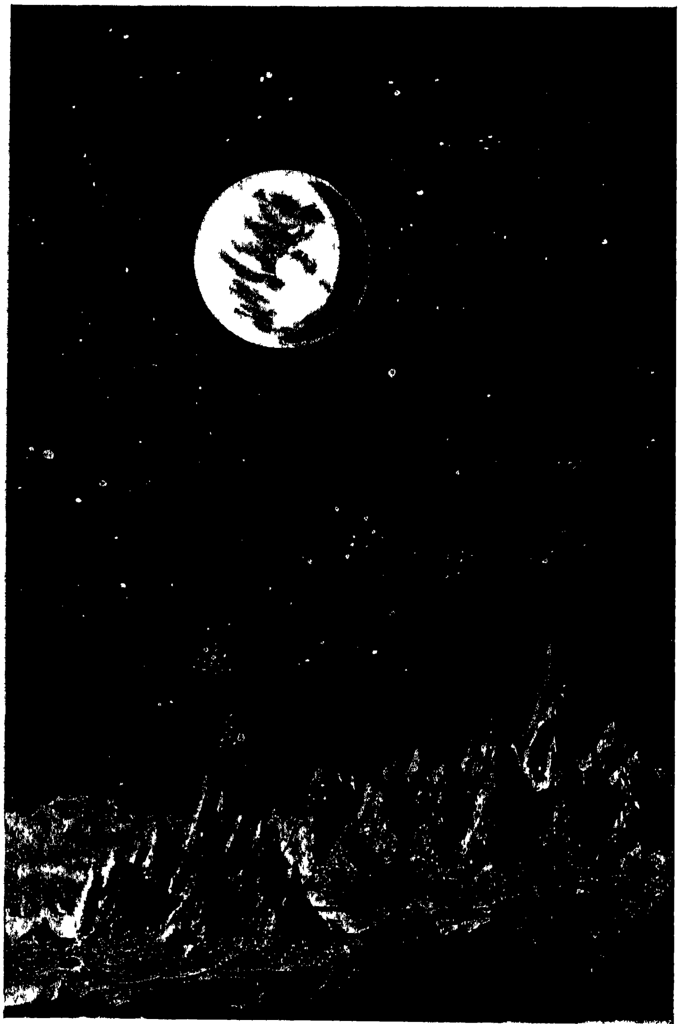


Photo by] [*Lick Observatory*

A PHOTOGRAPH OF THE FULL MOON

The Moon is really not quite Full, as some little shadow is seen in connection with objects near the left-hand edge This means it was taken a few hours after Full It shows the various "seas" as dark areas, and the positions which they occupy with respect to each other, and their situations on the disc

foundations of Selenography, that branch of Astronomy which concerns itself with the accurate delineation of the lunar surface details, and which has made such remarkable progress during the past 300 years, that now our knowledge of the Moon's surface is more complete than our knowledge of many parts of our own Earth. Some of these charts made by the earlier observers have come down to us, which, although from their crudity and lack of detail they possess little or no scientific value, testify to the zeal and persistence of their authors, who deserve every credit for what they were able to accomplish with the poor means at their disposal. These observers hoped in the course of time to be able to detect evidence of change on the Moon, and the same hope still animates the breasts of those who since then, and even now, are still pursuing this branch of Astronomy.



From a Drawing] [*By the Abbé Moreux*

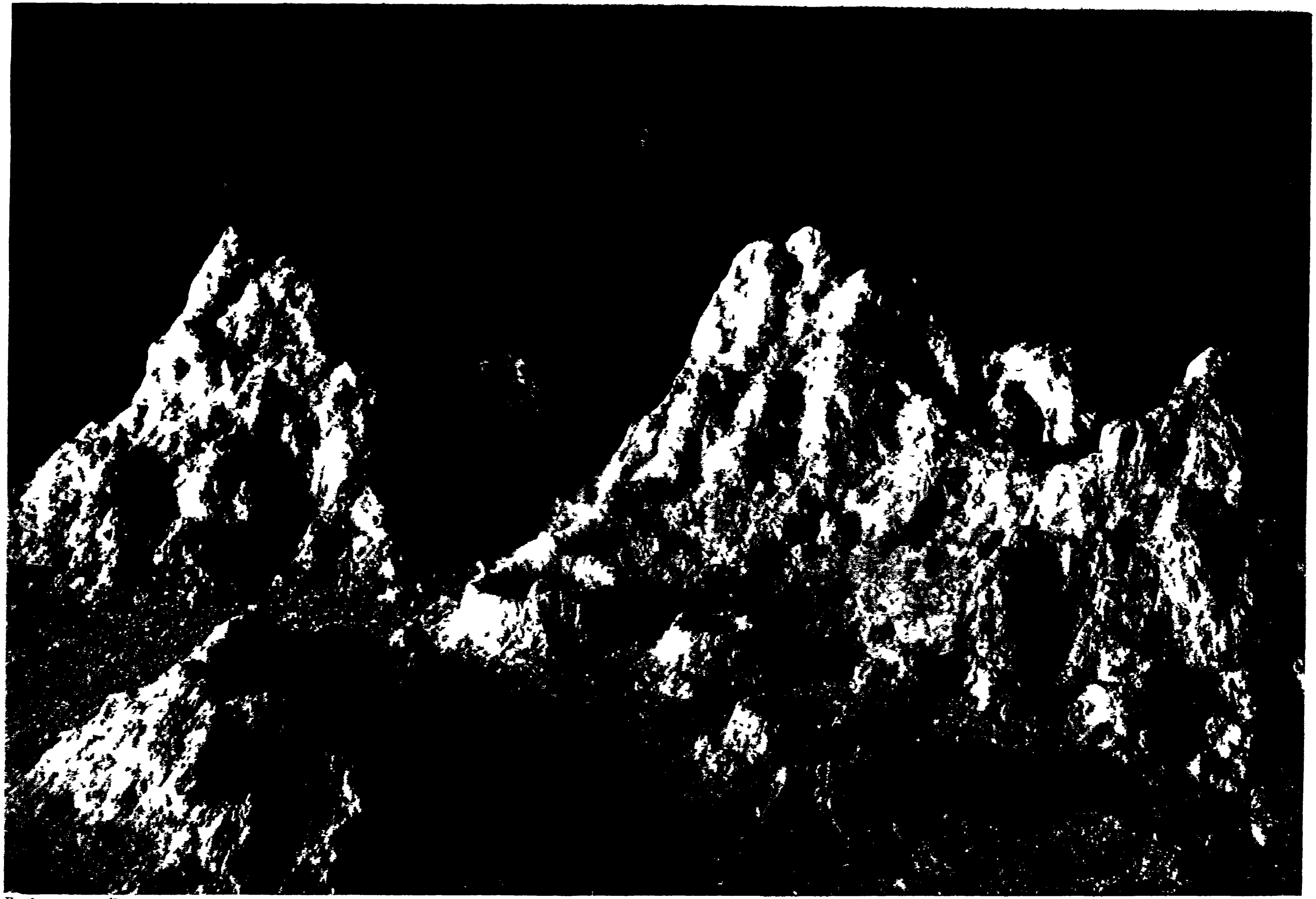
THE EARTH AS SEEN FROM THE MOON

In the foreground we have a typical lunar landscape with mountain peaks. The Earth is seen high in the lunar sky. The drawing also depicts small craters and a system of cracks in the surface, caused by shrinkage. The Earth would appear to the Lunarians thirteen times as large as the Moon appears to us, and the reflected sunlight would be greater in a still larger ratio.

It would occupy too much space to describe at length the history of Selenography, so that only the briefest outline can be given. Its progress was regulated by the telescopes in use from time to time, as these gradually increased in power and perfection, our knowledge of the Moon increased in a like ratio. No reliable and at all comprehensive maps of the Moon were produced before 1837, in which year Beer and Madler's map was published. This was thirty-seven inches in diameter, and founded on observations made during the years 1830 to 1837. It is a marvellous piece of work, considering that it was made with the aid of a telescope of only three and three-quarter inches aperture. Observers in England had however not been idle, and some valuable work was done by a number of amateur observers, under the direction of a committee appointed by the British Association, in an endeavour to construct a map of 200 inches to the Moon's diameter. This huge task was never completed owing to the death of Mr. W. R. Birt, the leader.

The next complete map after Beer and Madler's was one compiled by Schmidt of Athens, seventy-five inches in diameter, and containing far more detail than Beer and Mädler's. This task occupied Schmidt for more than thirty years. Subsequently, maps on a much smaller scale were published by two English observers, Neison and Elger. These were followed in 1910 by the writer's large map of the Moon—seventy-seven inches in diameter.

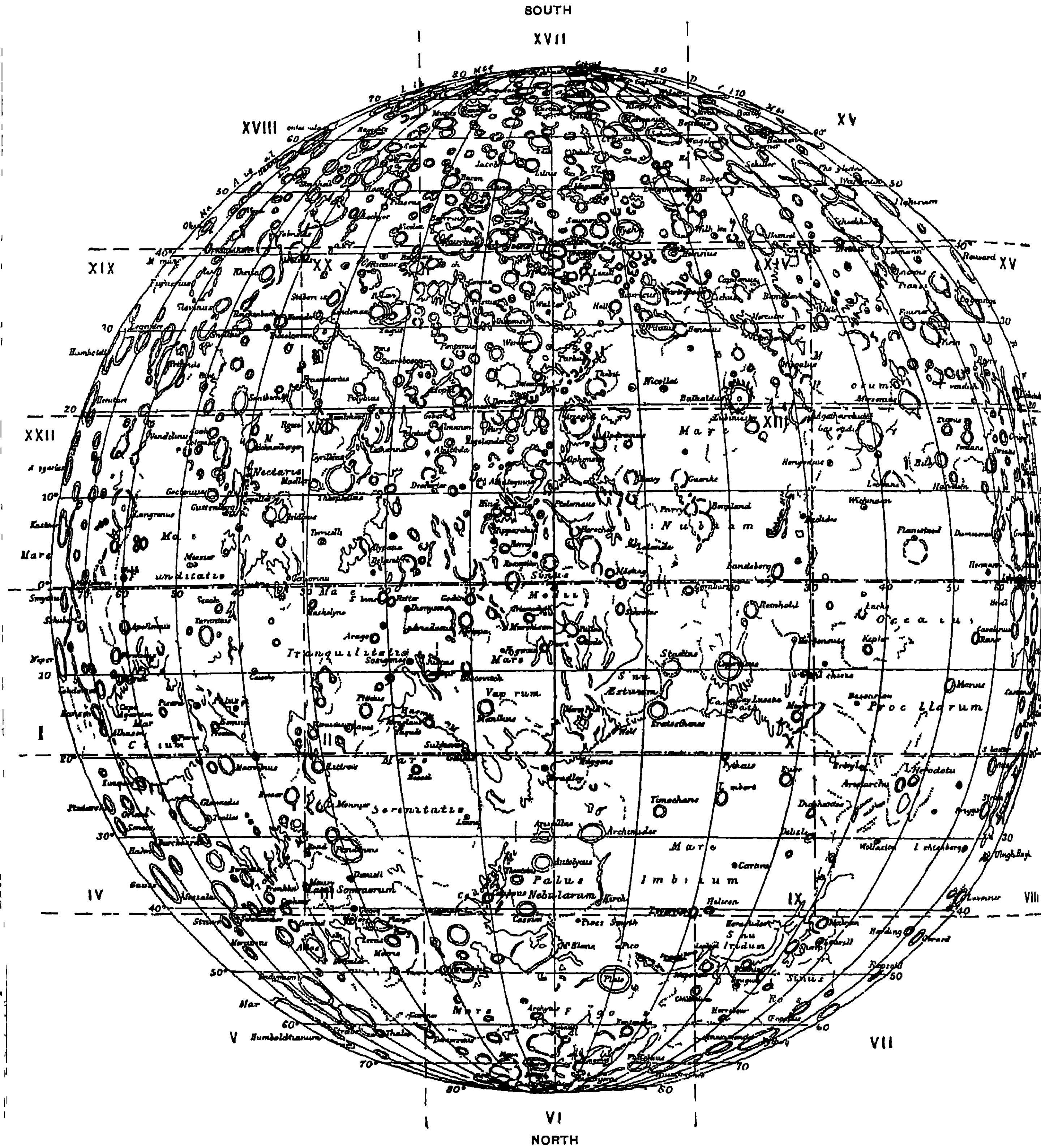
Within the last thirty years photography has been very successfully applied to producing pictures



By permission of] [L E A

A TYPICAL LUNAR LANDSCAPE

This shows in a very graphic way what the surface of the Moon would look like if we could view it at close quarters The Sun is seen to be rising, the small craters in the foreground being yet filled with darkness, whilst the flanks of the massive mountain, in all their ruggedness, are already bathed in light, the black sky would be resplendent with stars, notwithstanding the Sun is well above the horizon



[From Knowledge]

KEY MAP OF THE MOON

This shows on a small scale all the principal named objects on the Moon's surface and is therefore of great value as a work of reference in connection with any description of these features of our satellite The names attached to the various formations were given by the early observers Some names have also been added in recent times by other selenographers These names fulfil the useful purpose of enabling the observer to identify objects when using his telescope

of celestial objects, and in no case with greater success than in that of the Moon, several examples of these photographs appearing in this publication. Unfortunately these do not show the immense amount of detail which can be seen in the original negatives, a good deal of which is lost in the process of reproduction.

When the 60-inch telescope at Mount Wilson was ready for testing some years ago, photographs of the Moon were taken for that purpose, and they turned out to be by far the best representations of the surface secured up to that time, but even these fine results have been exceeded by the photographs recently taken with the new 100-inch telescope at the same observatory. These show much more and finer details than were previously shown, and a close study of them has revealed many objects now recorded for the first time. A complete photographic atlas of the Moon, taken by such an instrument, would not only be of the greatest interest to lunar observers of to-day, but would be invaluable if compared with similar pictures taken, say, in 100 years' time, with a view to discovering whether any change—and to what extent—had taken place in the interval, but at present there seems no prospect of this work being taken in hand, as the telescope is in constant use in other directions, where much more important problems await solution.

Photo by] [Lick Observatory

A PHOTOGRAPH OF A PORTION OF THE MOON

This shows the Mare Crisium just before sunset. It will be noticed that the western side of the Mare has partly disappeared from view in the shadow of the approaching night, whilst on the opposite side the shadows cast by the mountain border are very distinct.

The comparative nearness of the Moon and the absence of an atmosphere renders it the easiest of all telescopic objects, and enables its surface features to be seen sharp and clear, without the blurring effects which would be produced had we to look at it through an atmosphere such as surrounds the Earth.

The Moon, as seen by the naked eye at any time, but more especially when it is full, presents a bright disc mottled with light and dark patches, varying from intense brilliancy through varying shades of grey almost to blackness. If we look at the Moon through a pair of binoculars it will be seen that the dark areas predominate in the northern hemisphere, the southern half being much brighter on the whole. A still closer examination reveals the fact that the brightest regions are the mountainous portions, whilst the dark areas are comparatively smooth.

Anyone looking at the Moon for the first time through a telescope can hardly refrain from exclamations of surprise and pleasure at the wonderful scenes presented to his gaze. To see the Moon under the best conditions, that is when its rugged surface is visible, the observer should direct his telescope to it at any time between New Moon, when its narrow crescent is first seen in the west, and

a day or two before it is Full, and a similar interval after Full and the next New Moon The ruggedness is best seen near the "Terminator"—that region which separates the bright surface from the un-illuminated part of the disc Along this region the Sun is just rising or setting on the Moon, and every irregularity of the surface is thrown into strong relief—the mountains and crater walls throwing their long, tapering shadows in a direction opposite the Sun, and for many miles these shadows are very black, there being no twilight to modify their intensity It is indeed by measuring the length of these shadows that the height of the mountains on the Moon has been determined

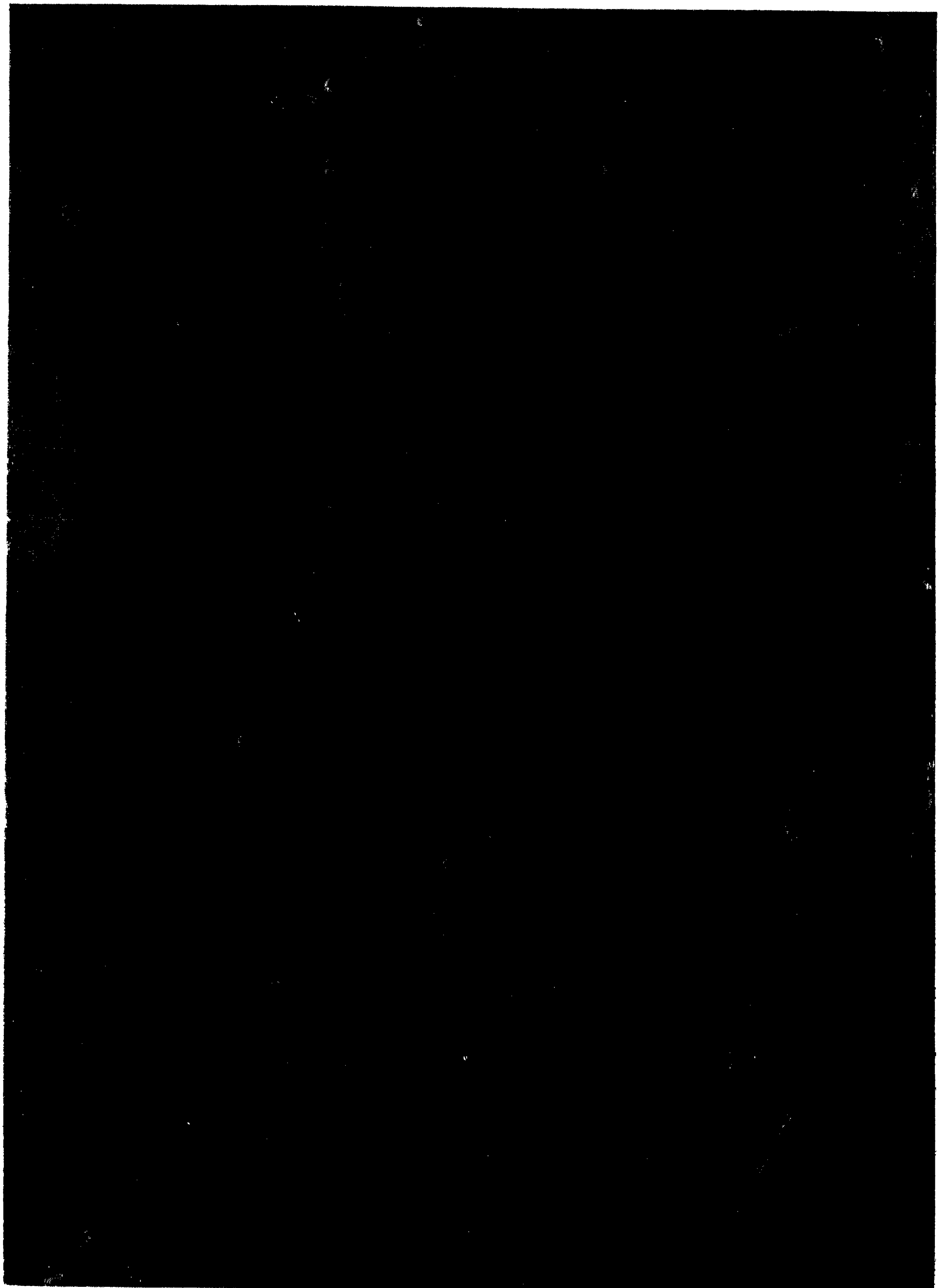
It is sometimes asked what is the smallest object that can be seen on the Moon To form some idea we must take into account the Moon's distance, which, in round figures, is about 240,000 miles If we direct a telescope to the Moon, having an eye-piece capable of magnifying 1,000 times, this would be equivalent to bringing the Moon to within 240 miles of the Earth It will be at once realised that however well illuminated, we could not make out any detail with the naked eye upon an object 240 miles away, on the Earth, and besides this, there are few telescopes that will stand a magnifying power of 1,000 and give good definition, not because of any imperfection in the instrument, but because atmospheric tremors would spoil the sharpness of definition This unsteadiness of our atmosphere acts in severely limiting the utility of our telescopes in their application to the heavenly bodies Hence astronomers are always looking out for locations for their observatories where they can rely, not only on freedom from clouds, but on a still air

From a Photo by] [*MM Loewy and Puiseux, Paris Observatory*

A PHOTOGRAPH OF THE MOON AT ABOUT SEVEN DAYS OLD

It well represents the aspect presented in a small telescope and shows the rugged surface of the southern hemisphere (which is at the top) At the lower portion the Lunar Alps and Apennines are just coming into view at sunrise

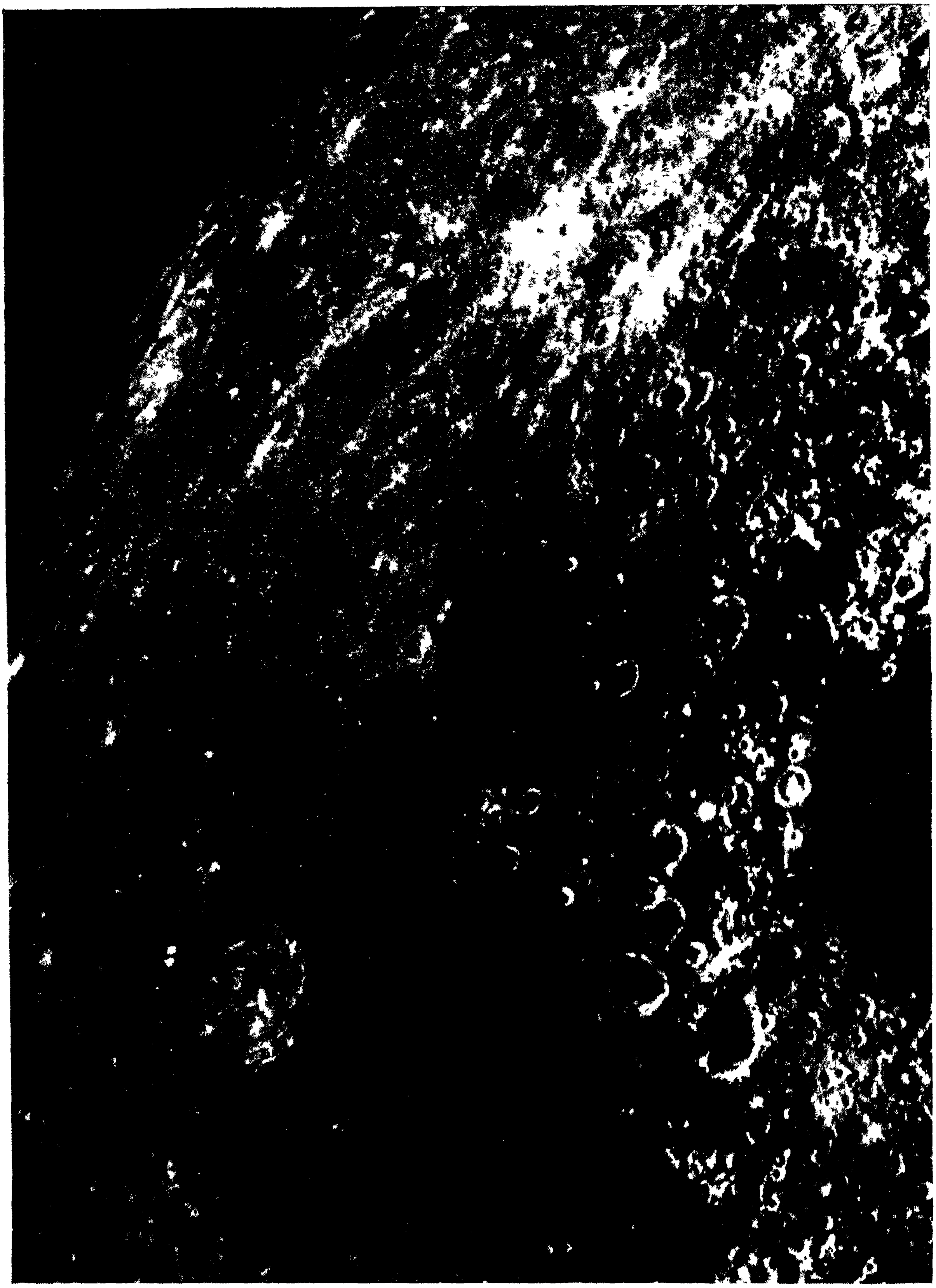
It is generally agreed that the most powerful telescope used under the best conditions would just reveal the existence of an object not less than 100 yards in height and length, and then only by reason of the shadow it would cast under the slanting rays of the Sun Probably an object the size of



From "Knowledge"] [*Taken at the Paris Observatory by MM Loewy and Puiseux*

A PHOTOGRAPH OF A PORTION OF THE MOON

This picture was taken a few days before sunset, at the time of the waning Moon The declining Sun has already caused the craters on the left-hand side to become filled with shadow The upper part shows the crater Kepler, with its system of bright rays, and lower down we have the crater Aristarchus, one of the brightest spots on the Moon, now only visible under the high Sun as a bright patch with a number of rays emanating from it At this particular region of the Moon no mountains exist that can be seen in profile on the limb



From "Knowledge"] [*Taken at the Paris Observatory by MM Loewy and Puiseux*

A PHOTOGRAPH OF A PORTION OF THE MOON

This represents the aspect of the surface when the Moon is about seven days old The larger portion is seen with the Sun overhead, consequently, nothing is visible in relief More relief is found near the right-hand edge, where the Sun has not reached such a great elevation in the lunar sky

the largest pyramid in Egypt or St Paul's Cathedral could be made out as a slight irregularity on the surface, but without anything to show its real shape or nature

Many efforts in times past have been made to try and discover the existence on the Moon of the works of animated beings, and some of the old observers, with their feeble instruments, claimed to have detected objects which were of artificial construction, but these views were dispelled by later observers using more powerful optical aid It was found that these formations were much too large to have been thus formed, and must be ascribed to natural causes There is one such object that may be mentioned It is situated near the centre of the disc, being about 65 miles in length and 500 feet in height, described by some as the "straight wall," and by others as the "railway line" It is well shown on the upper part of the photograph opposite page 53 If it is viewed through a small telescope when seen near the terminator, it appears to be a perfectly straight line, which would easily suggest its artificial origin, but when examined in a powerful telescope it is seen not to be quite so straight as it first appeared It has many bends and curves in its length and is also very irregular in its height In reality it is one side of a line of cliffs, caused by a fault in the surface, which has subsided to a depth equal to the height of the exposed cliff

From a Drawing] [*By Krieger*

CLEFTS ON THE MOON'S SURFACE.

This is a fine example of the systems of Clefts which abound on the Moon, and as drawn by the late J N Krieger, based on a photograph The large crater ring is known as Triesnecker It will be noticed that the clefts seem to emanate from a point just to the west of this formation

Other instances might be mentioned where the old observers found rectangular areas surrounded and enclosed by low walls, suggesting ramparts Other objects consisted of several ridges running parallel to each other, and also looking like artificial formations, but these are merely fanciful ideas not supported by facts

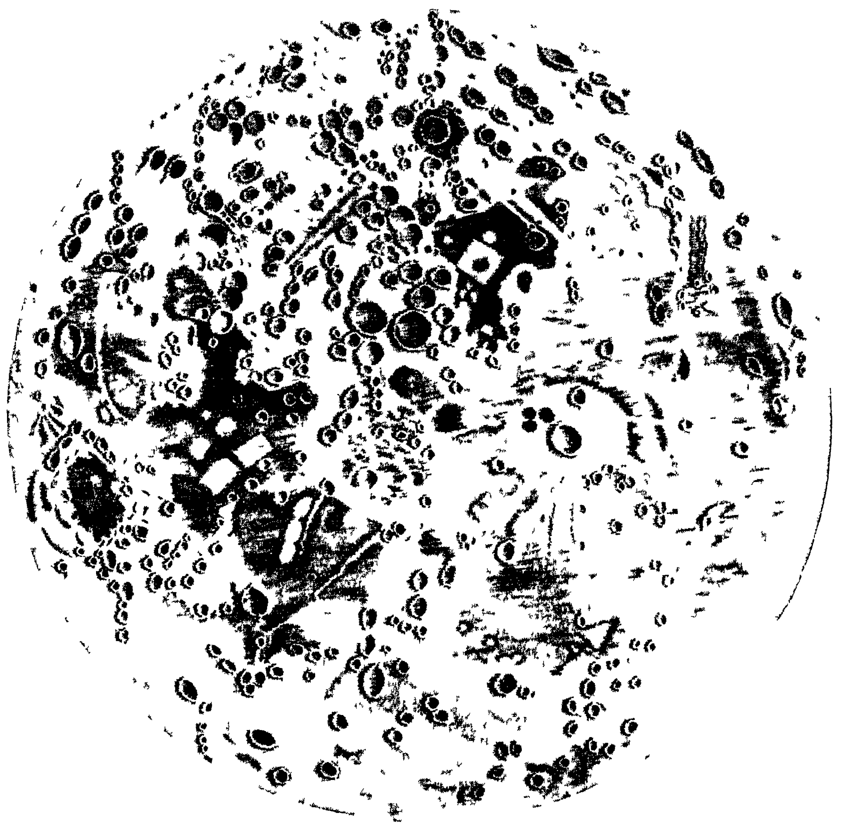
From these considerations let us now turn to the study of the various objects we find by our telescopes to occupy such a large space on the Moon The most prominent may be classified under the following heads -

- The large dark areas or plains which the ancients described as Maria or Seas, and the ridges which are associated with them
- The mountain walled plains
- The crater-like objects, mostly of large size
- The ring-plains, craters, crater cones, craterlets, crater pits, valleys, clefts or cracks, and mountain ranges
- The wonderful systems of bright rays or streaks

From this catalogue it will be seen that there is no lack of variety in respect of the objects we find on the lunar surface We commence with the *Maria* or Seas If we examine a photograph of the Moon taken at or near Full, of which photographs there is now a large number, we are at once

struck with the considerable portion of the surface which is covered by these dark areas, and we notice, further, that they predominate in the northern and eastern portions of the disc It is also worthy of note that none of the dark areas extend as far as the edge or limb Most of these dark areas communicate with each other, having no separate definite boundaries To this rule, however, there are two conspicuous exceptions one is the Mare Crisium (the Sea of Crises) in the north-west, a circular dark area surrounded by a bright mountainous country, the other is known as the Mare Humorum (the Sea of Humours), in the opposite or south-east portion of the disc, and slightly smaller in size

Three other roughly circular plains lie to the east of the Mare Crisium, and, connected with each other, extend in a chain almost across the entire disc These are in order from west to east the Mare Tranquilitatis (Sea of Tranquility), the Mare Serenitatis (Sea of Serenity), and the Mare Imbrium (Sea of Rains)



OLD CHART OF THE MOON

This is a copy of the chart made by Cherubin D'Orléans, in 1671 It has no scientific value, but is a good example of the work of the early selenographers and represents the results of much time and energy spent on observing the lunar surface The difference between this and a modern map is very great, as will be seen on comparing the same

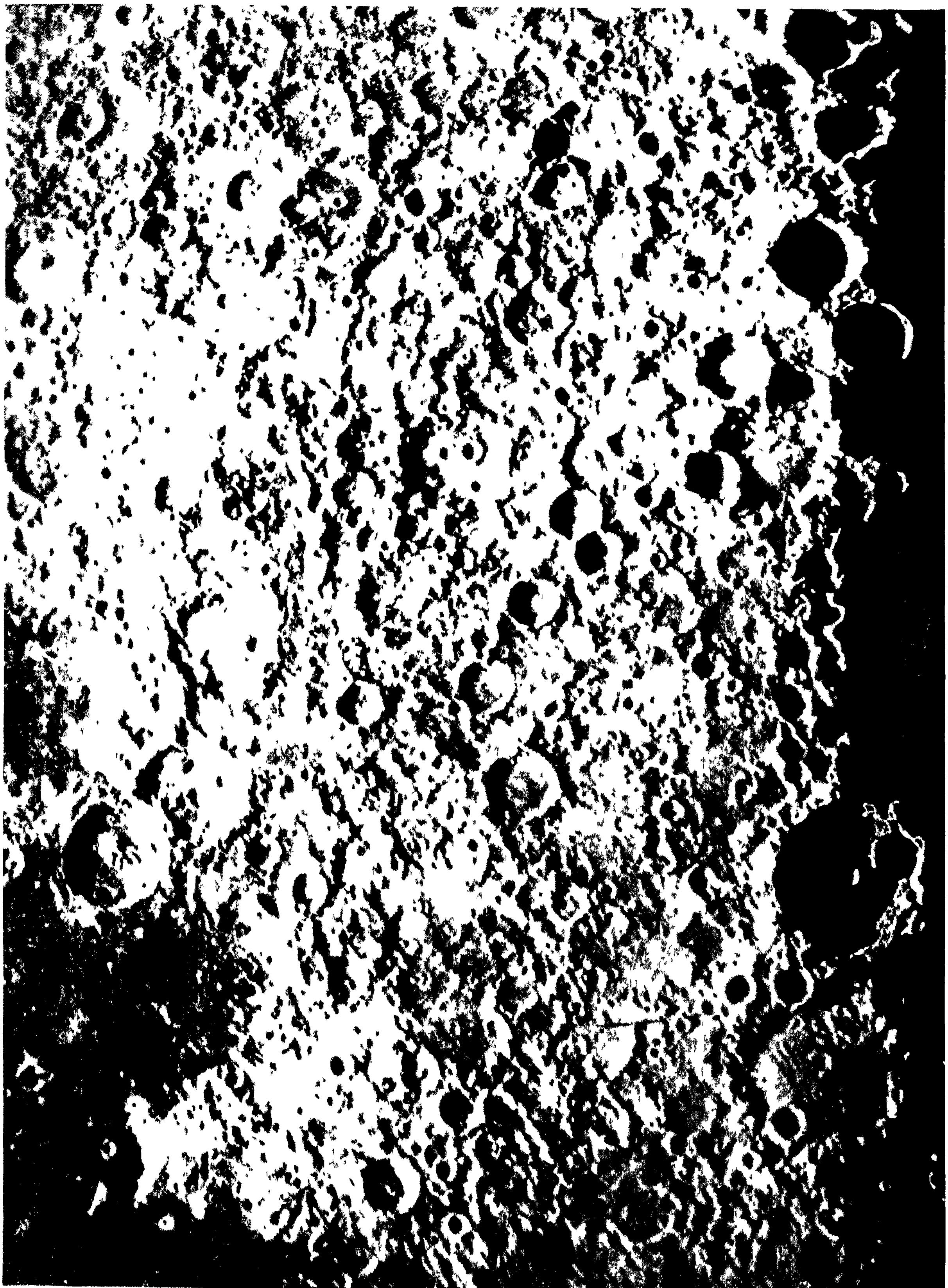
When these vast areas are scrutinised through a small telescope, they appear to have smooth surfaces, devoid of any but the smallest irregularities This impression is quite illusory, as when examined with a powerful instrument, especially when either of them is crossed by the terminator—that is when the Sun's rays fall on them obliquely, either when rising or setting—it will be found that they abound in hollows and sinuous low rounded swellings or ridges extending for many miles The real surfaces of these plains resemble in many ways the great prairies of America The ridges referred to rise in places from 150 to 700 feet, but become invisible when the Sun has risen to some extent in the lunar sky Other portions would, on a nearer view, be found to be covered with minute asperities, like the terrestrial lava fields

The following is a list of the principal Maria or Seas on the Moon —

Mare Australe, Crisium, Foecunditatis, Frigoris, Humboldtianum, Humorum, Imbrium, Nectaris, Nubium, Serenitatis, Tranquilitatis, Vaporum, Smythii, and the Oceanus Procellarum

In addition, there are a number of other and smaller dark areas, prefixed by the words Sinus, Lacus, and Palus, and which are more particularly described in text-books on the Moon

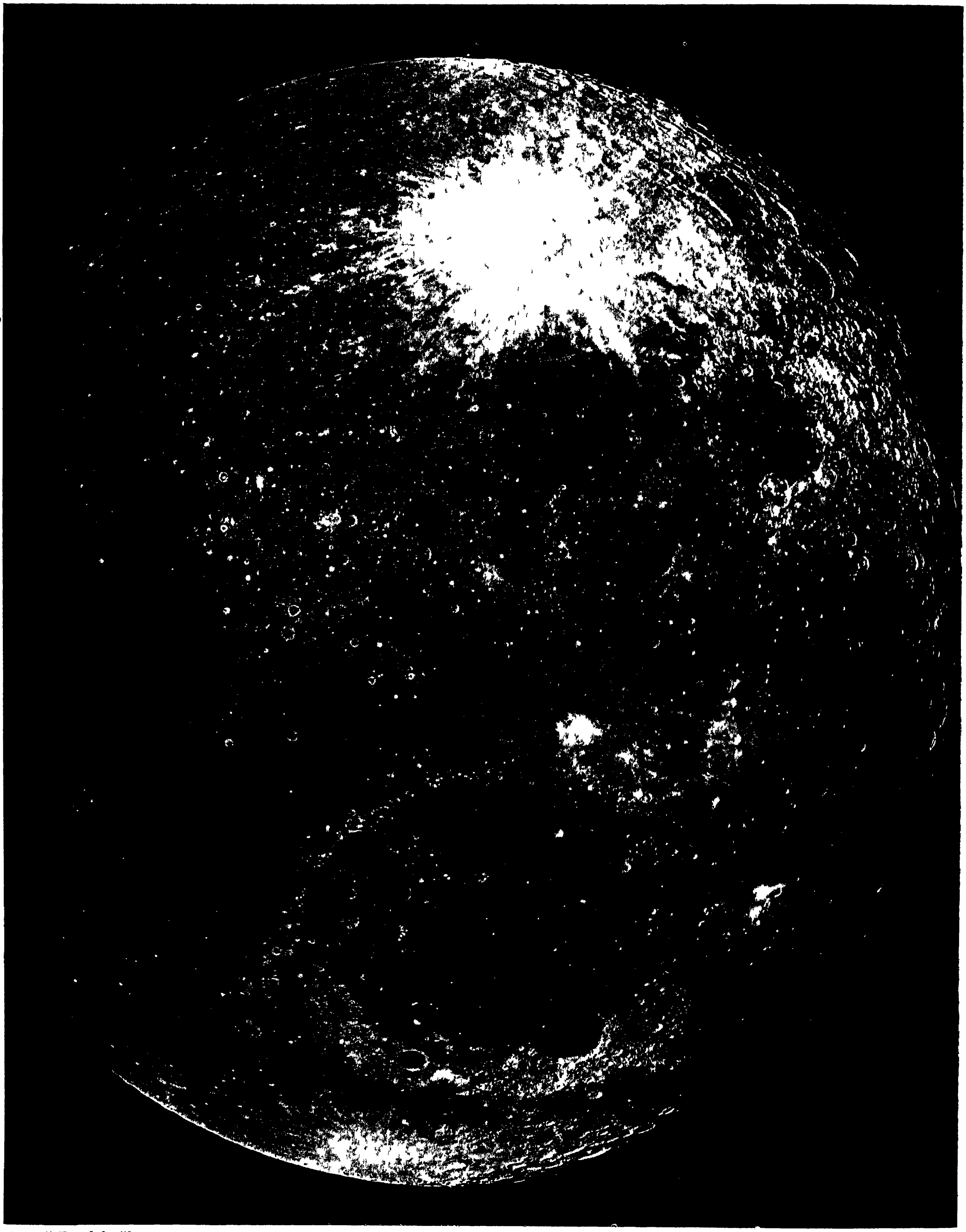
The great expanse of these so-called seas may be inferred from the fact that the Mare Crisium has



From "Knowledge"] [*Taken at the Paris Observatory by MM Loewy and Puiseux*

A PHOTOGRAPH OF A PORTION OF THE MOON

Taken when the Moon was nearly at its First Quarter The large ring plains on the right are still in shadow, the rising Sun having just touched their mountain ramparts into visibility The greater portion of the surface thus shown lies to the south of the equator and is of a rugged nature On the left and near the bottom is the large ring plain Theophilus one of the finest of its class on the Moon, and a rival to Copernicus Its inner terraced walls and multiple central mountain are easily seen



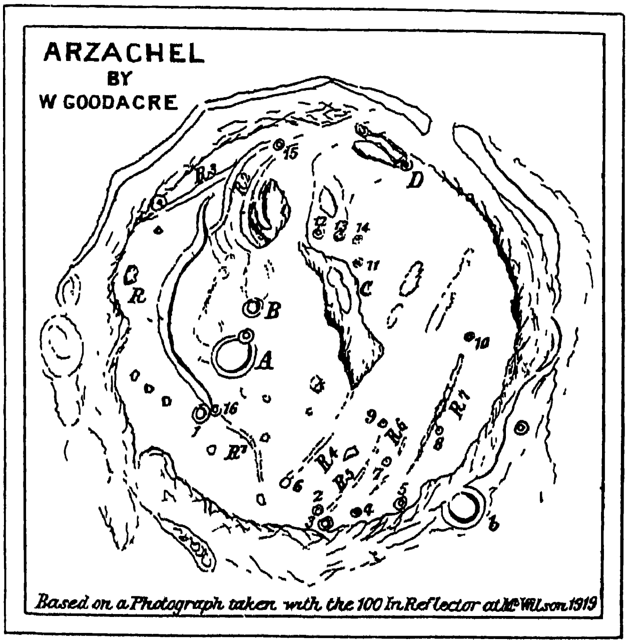
From "Knowledge"] [*After Puiseux*

A PHOTOGRAPH OF THE MOON

Taken when the Moon was nearly Full. The Sun is rising on the formations near the extreme right hand (E.) limb; left of the centre it is shining overhead. This photograph shows the principal systems of bright rays. The chief and most conspicuous are those associated with Tycho, which is found as a bright ring near the top of the photograph. Below it, and near the centre, we find the rays radiating from Copernicus, and to the right of Copernicus is the Kepler system.

an area of roughly 78,000 square miles, being nearly 300 miles from north to south, and 350 miles from east to west, whilst the Mare Serenitatis is nearly circular, being 433 miles from north to south and 424 miles from east to west, and contains approximately 125,000 square miles, whilst if we take the Mare Imbrium, the greatest of the circular plains, we find a length of about 750 miles and a breadth of 700 miles, which gives an area of about 340,000 square miles Further, it may be mentioned in respect of the Oceanus Procellarum, the most extensive of all the seas, but with very indefinite boundaries, the area cannot be less than 2,000,000 square miles The forces which produced these great expanses will be dealt with later

Ridges —These curious serpentine banks already referred to are found almost solely on the great plains or seas, are in many cases concentric with their borders, but in other instances they are seen to traverse the surface in various directions, being subject to no well-defined arrangement Rarely are they found to be straight, but serpentine, with many bays or inflexions in their course Frequently they throw out arms or branches and are often associated with small craters, which are found on their flanks or summits They are no doubt folds in the surface, and, it has been suggested, mark the places where cracks formerly existed, and through which molten lava has been extruded on both sides On the other hand, some of these ridges form segments of circles, suggesting they are all that is now left of once complete mountain ridges, which have been reduced and partly destroyed by the action of lava at the time the seas were formed Some of the most remarkable of these objects will be found on the borders of the Mare Humorum, and also in the Mare Nectaris, where there is quite a network of them, but all the plains show them to a greater or less extent, and they are quite conspicuous on some of the lunar photographs, they vary in length, but one to two hundred miles is not uncommon



This is a chart of the mountain ringed plain Arzachel, and shows the modern method of depicting the details of the lunar surface Arzachel is about sixty five miles in diameter The chart gives many objects recorded for the first time by means of photography

Craters and Crater-like objects —These are the most numerous, and, generally speaking, the most striking objects to be found on the Moon They present a wide range of size and shape, from the large mountain rings to the smallest crater cones of a few hundred yards in diameter In general form they are approximately circular, but in the largest ones considerable departure from the circle is obvious If these are examined closely with a powerful telescope it will be seen that the surrounding mountain wall is often polygonal, rather than circular, suggesting that whilst the original form was that of a circle, pressure from without or within has forced the line of the ramparts into more or less lineal sections, standing at various angles to each other

These crater-like objects have been divided into several classes, according to their individual characteristics We commence with the walled plains These represent the largest enclosures, from 60 to 150 miles in diameter They are generally encircled by mountainous ramparts, rising in some cases to 12,000 feet above the interior These ramparts are very complex in structure, their continuity being broken by valleys and broad passes, and with many terraces on the inner slopes, and many evidences of landslips from the same The level interior of these enclosures is broken in nearly all

cases by large craters, groups of mountains, and isolated peaks, ridges, clefts and crater-like depressions

The large walled plains have many of the characteristics of the smaller Maria, and have by some authorities been placed in the same category They probably owe their existence to the same forces which formed the lunar seas The following are examples of these objects Clavius, the largest, followed by such as Petavius, Furnerius, and Langrenus, in the south-west quadrant W Humboldt, Cleomedes, Gauss, and Endymion, in the north-west quadrant In the south-east quadrant, where they are most numerous, we have Maginus, Longomontanus, Shickhard, Walter, Pitatus, Ptolemaeus, Grimaldi, and Riccioli

The next class of objects claiming our attention is the Ring Plains These differ from the walled plains in that they are smaller, with more symmetrically circular walls They are also more numerous, and their appearance suggests very strikingly the probability of their volcanic origin Their surrounding ramparts are high and very massive, and fall with steep declivity to the interior floor The walls on the exterior, on the other hand, rise with a gentle slope from the surrounding country These outer slopes are however very rugged, and in many cases traversed in a radial manner by what may be lava ridges with deep intervening valleys, which sometimes are found to consist of chains of small craters On the summit of the walls, peaks of considerable elevation are often found The inner slopes are very frequently broken by a series of terraces, which descend one below the other till the floor is reached These terraces are separated from each other by yawning crevasses of unknown depth, and are in all probability caused by the action of molten lava in the interior undermining the walls, and so causing large portions to slip down from time to time The most striking and perfect object in this class is the well-known crater called Copernicus, fifty-six miles in diameter, and standing in an isolated position between the Mare Nubium and the Mare Imbrium Some wonderful photographs of this formation have been secured at Mount Wilson by the use of the 100-inch Hooker Telescope They reveal much detail and give a splendid view of this most noble object A study of these photographs brings some interesting facts to our notice It will be observed that the crest of the wall is not circular, but is broken up into a number of straight ridges and curved sections, but all fairly uniform in height According to Neison, the walls rise above the interior some 12,000 feet At the centre is a group

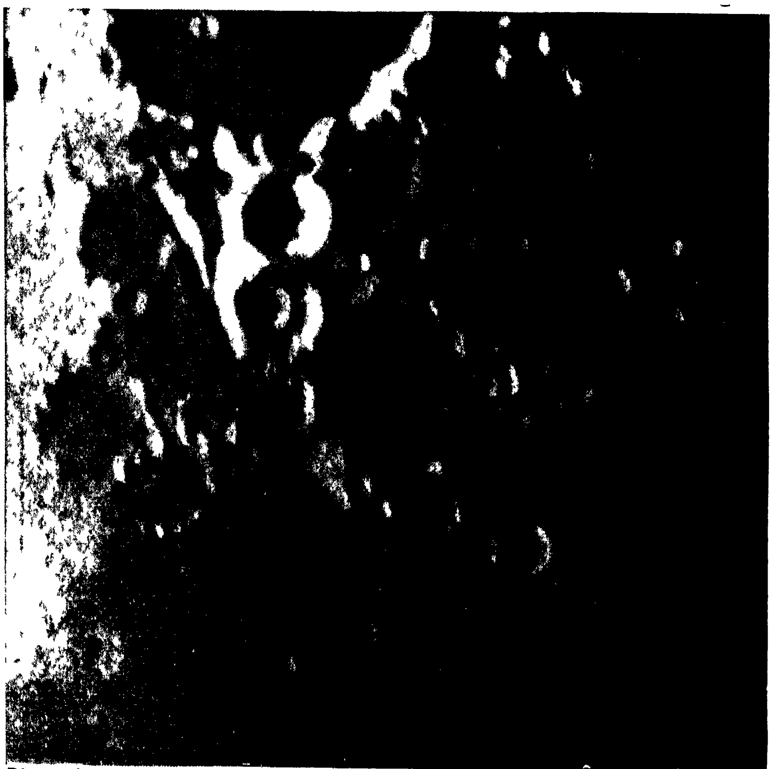
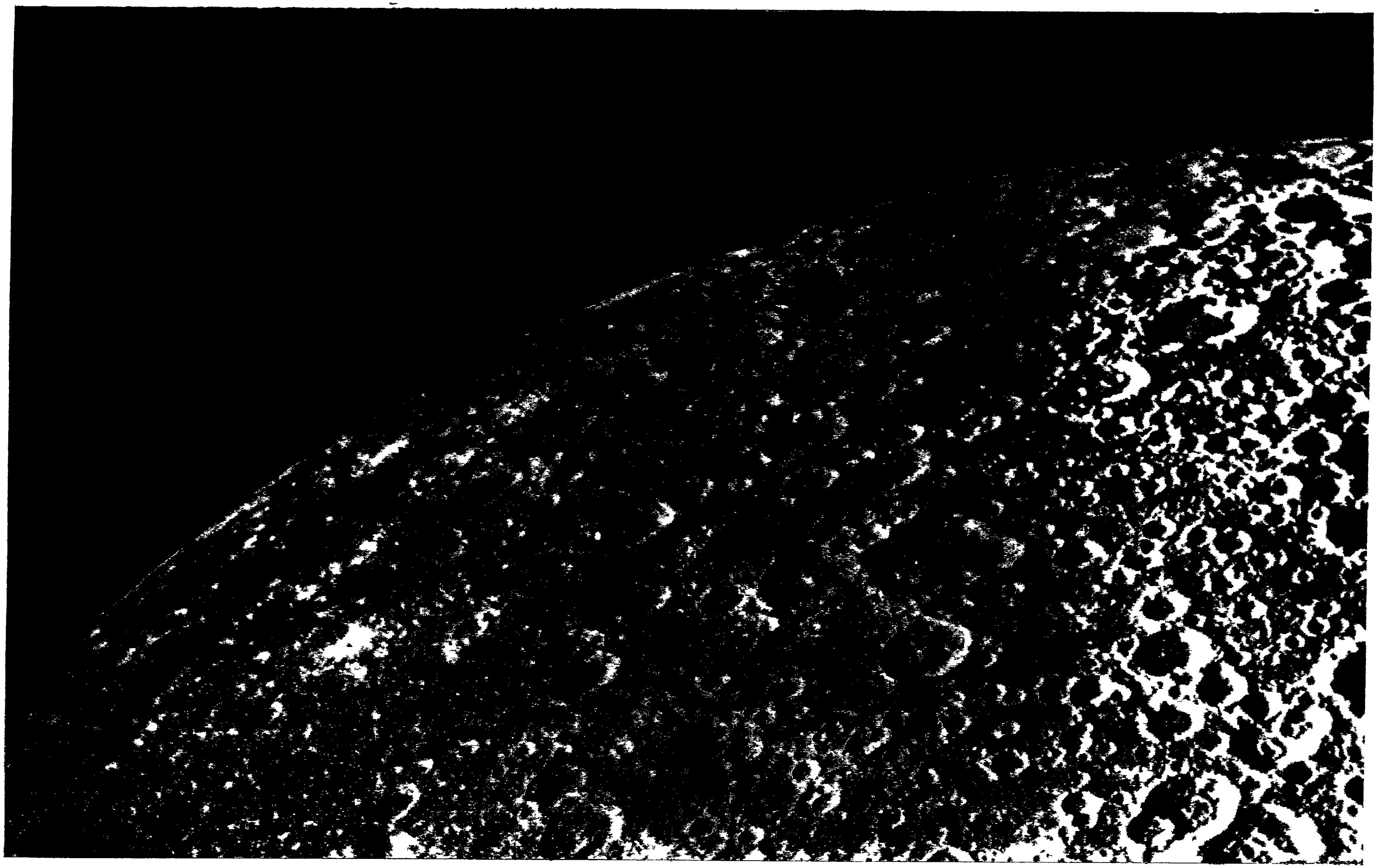


Photo by] [*C Flammarion*

A PHOTOGRAPH OF A PORTION OF THE MOON

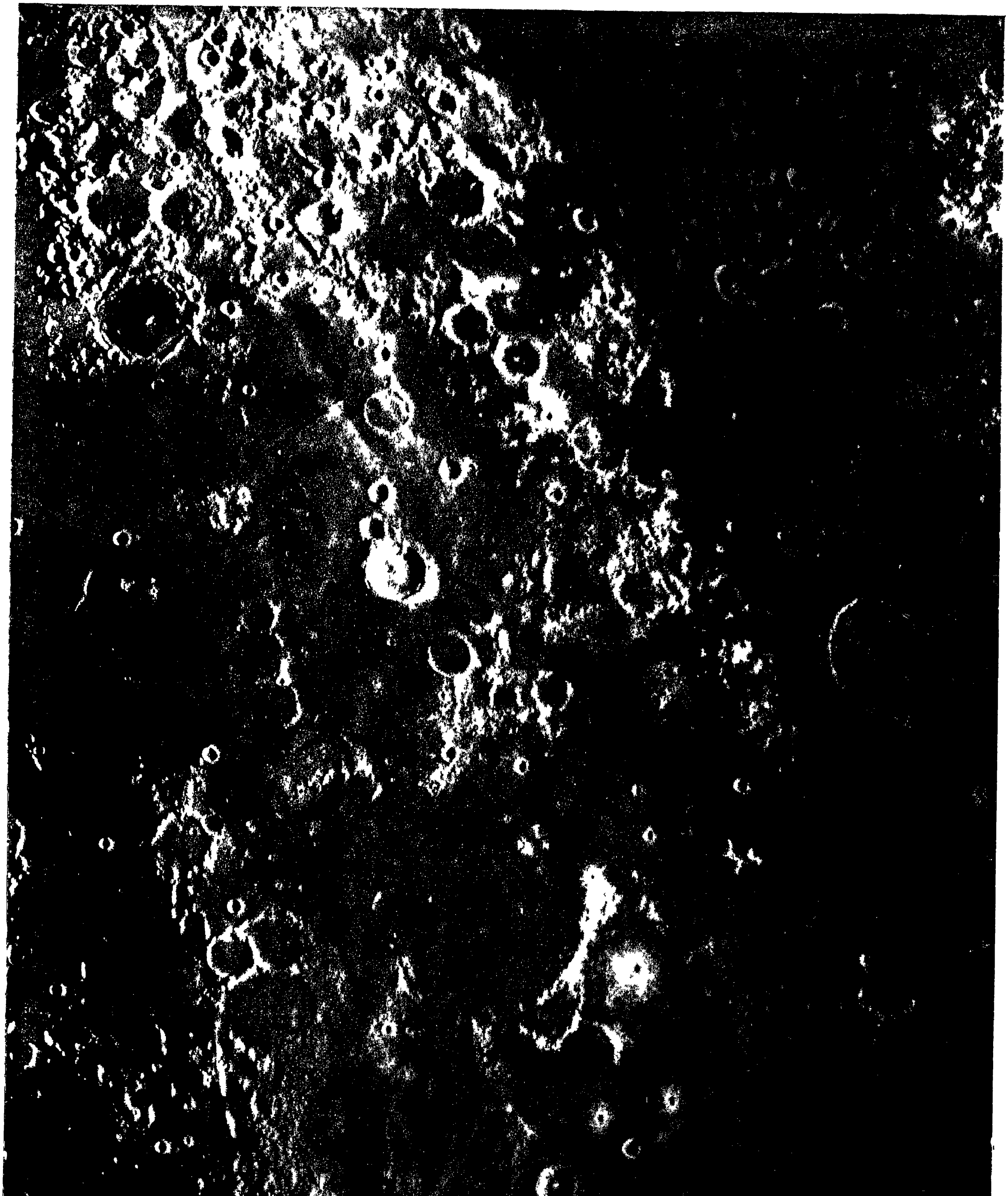
The upper part shows the northern half of the ring plain Ptolemaeus The well-formed ring, partly filled with shadow, which is in contact with its northern rampart, is named Herschel, after the great astronomer A little to the right and below Herschel is a large roughly-circular enclosure, with a smooth dark floor, and very broken walls, and is named Flammarion, after the well-known French astronomer of that name



From "Knowledge] [*Taken at the Paris Observatory by MM Loewy and Puiseux*

A PHOTOGRAPH OF A PORTION OF THE MOON

Showing a region to the south-west many of the larger mountain rings are fifty to sixty miles in diameter The southern half of the surface of the Moon is covered over with innumerable crater-like depressions of all sorts and sizes, and the photograph illustrates this characteristic in a very marked manner Some of the larger rings it will be noticed are quite smooth, whilst others have large irregularities on their surfaces The photograph is taken under a rising Sun, as shown by the shadows lying to the east



From "Knowledge" [*Taken at the Paris Observatory by MM Loewy and Puiseux*

A PHOTOGRAPH OF A PORTION OF THE MOON

Taken towards sunset, as shown by the lengthening shadows on the left hand side Some of the deeper craters near the Terminator are already filled with shadow The dark surface of the M Humorum is shown to the upper right-hand side, with Gassendi on its lower margin Near the centre is Bullialdus, with several specimens of ruined rings around it, on the surface of the M Nubium Faint indications of the Hesiodus Valley, also of the valleys to the west of the M Humorum, can be traced For the names of the other prominent features, reference should be made to the key map

of mountains, of which seven peaks can be counted These are probably the ruins of a single mountain of considerable size, shattered by the force of volcanic energy, which was unable to escape through its central orifice On the southern half of the floor are a number of hills, which a closer inspection would probably reveal as crater cones The northern half of the floor is comparatively smooth

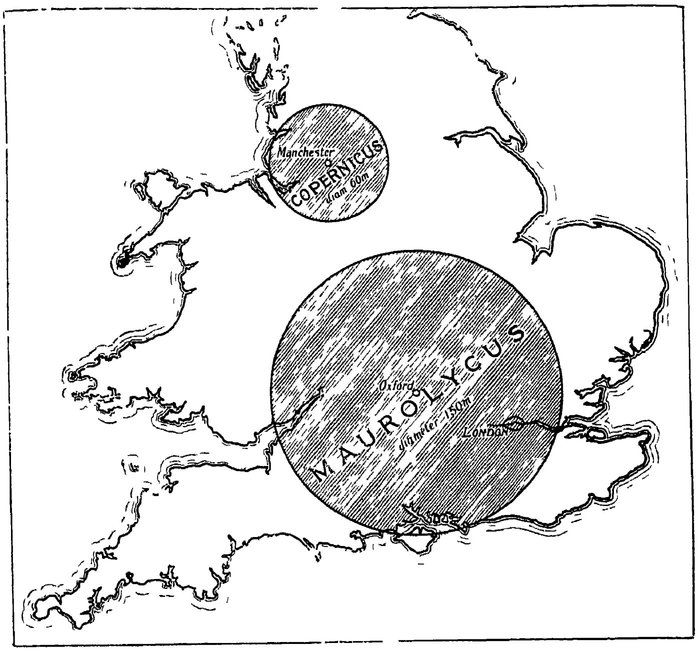
There are numerous other formations on the Moon very like Copernicus, and quite as large, which would present a similarly grand spectacle if they were as well placed on the disc We may refer to Theophilus, sixty-four miles in diameter, Bullialdus, thirty-eight miles in diameter, Aristillus, Langrenus, Petavius, and Eratosthenes, all of which are well shown on the various lunar photographs now in existence

Craters —These are a subdivision of the crater rings and other objects just described In most cases the difference is slight and the division therefore difficult Whilst possessing most of the characteristics of the ring plains, they are smaller, and in form more truly circular In diameter they vary from fifteen to three miles or less The outer walls rise more steeply to the summit, and the descent on the inner side is equally abrupt They are found on every part of the lunar surface, and probably originated at a time when volcanic energy first began to wane Many have a brighter and newer aspect than the locality in which they stand, and not infrequently they are surrounded by or stand on a small bright area encircling them like a halo

It is generally assumed that the bright area consists of whitish ash or material ejected from the volcano itself Whilst to the casual observer the ring plains and crater rings seem to be distributed over the lunar surface in a haphazard manner, the careful student will not fail to note that this is not quite the

TWO GREAT VALLEYS ON THE MOON

This photograph shows two of the most interesting valleys, or clefts, on the Moon The one to the left is known as the Aridaeus Cleft, which runs for a very long distance E to W Below it is a horse-shoe formation named Julius Caesar To the right is the well-known Hyginus Cleft About one inch on the photograph below this, but obscured by the shadow, is a spot known as Hyginus N , which about thirty years ago was declared by Dr Klein to have been recently formed His contention has, however, never been satisfactorily established



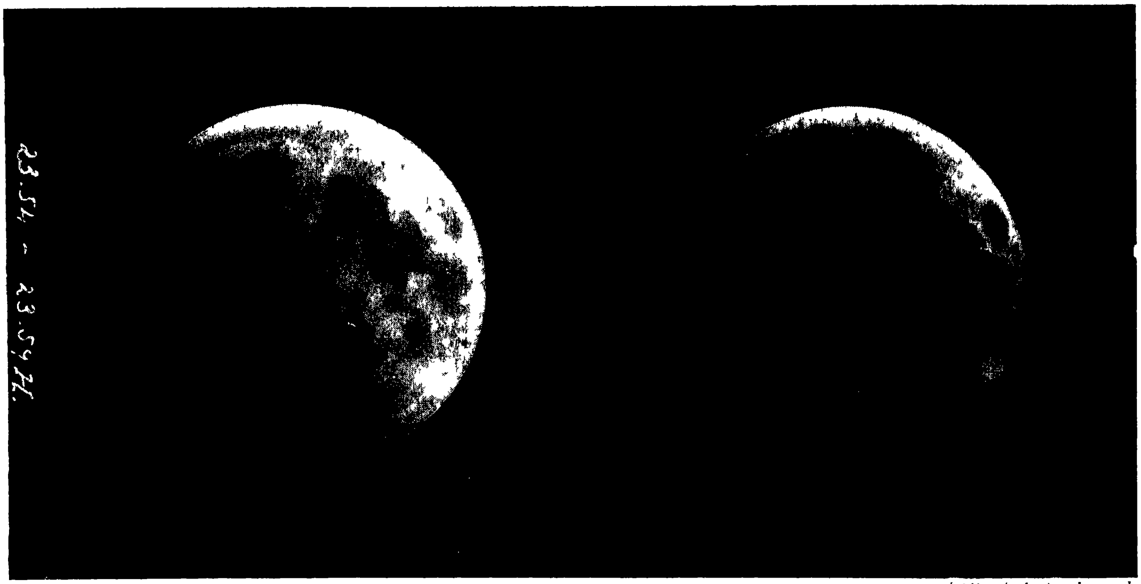
COMPARISON OF THE SIZES OF TWO OF THE LUNAR MOUNTAIN-RINGED PLAINS, AND THE AREA OF ENGLAND AND WALES

Maurolycus is a great plain of 150 miles in diameter, surrounded by a rugged mountain rampart rising to the height of 12,000 feet above the interior

case He will see, for instance, that crater rings or ring plains are often found in pairs, in which the individuals strongly resemble each other Take for illustration, Atlas and Hercules Aristoteles and Eudoxus, Aristillus and Autolycus, Sabine and Ritter, and among the smaller objects, Beer and Beer A

Central Peaks—These mountain masses are common to nearly every kind of enclosure on the Moon, from the large mountain-encircled plains to the smallest type of crater ring A careful inspection of the Moon, even by a small telescope, or the study of a good photograph, will not fail to reveal the fact that in a very large number of cases at the centre of the ring there is a mountain mass sometimes consisting of one peak, and in other cases of a multiple peak These central mountains are of considerable size and great elevation Attention may be called to a few typical instances

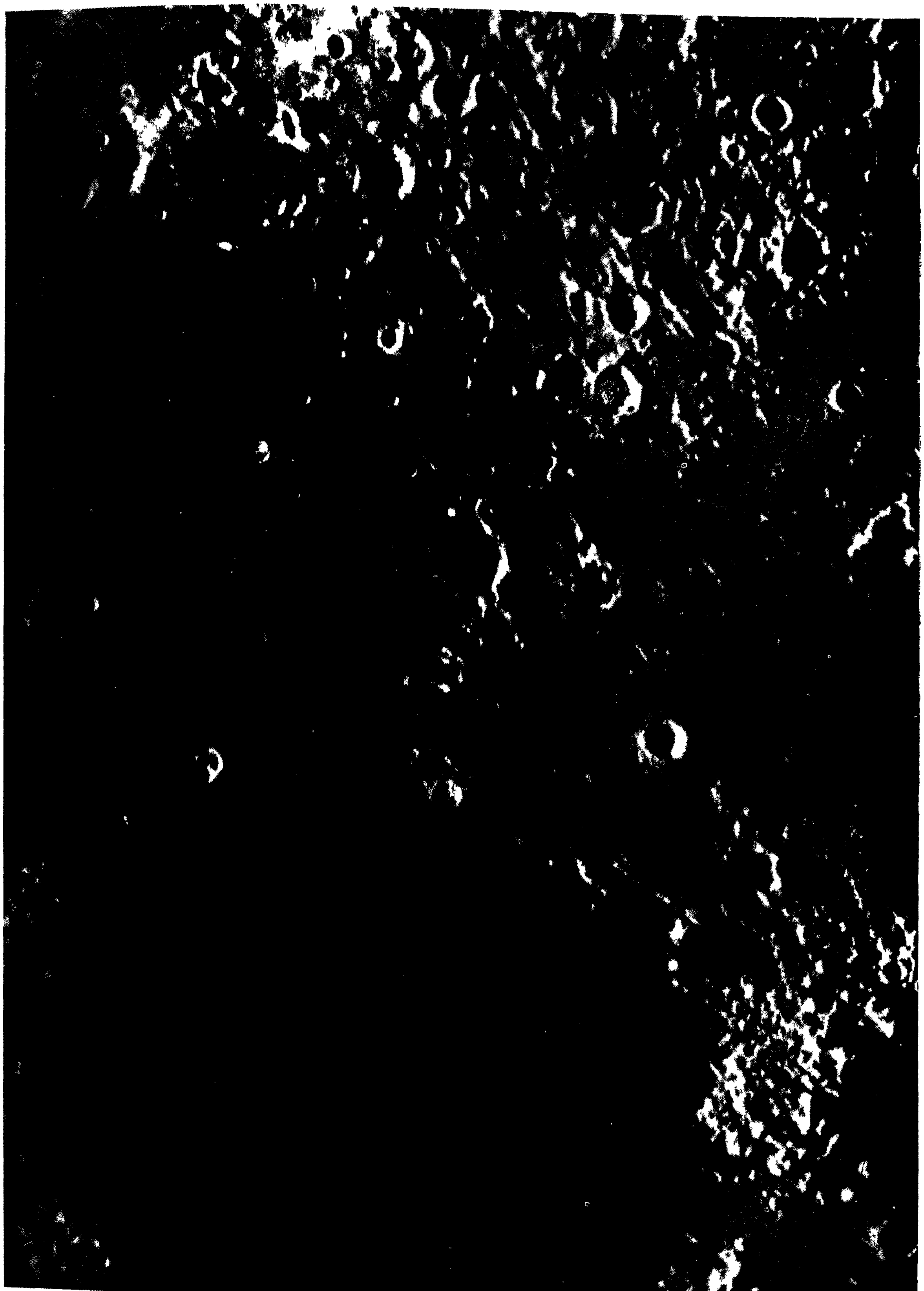
If the crater Tycho is examined, a central mountain mass is seen at once, and on one of its flanks a smaller elevation This latter is very easily seen sometimes, and at other times is invisible in small telescopes On the summit of this smaller mountain a crater has been found The large central mountain



From "Knowledge"] [*After Salvator Raurich*

STEREOGRAM OF THE MOON'S ECLIPSE, 1909

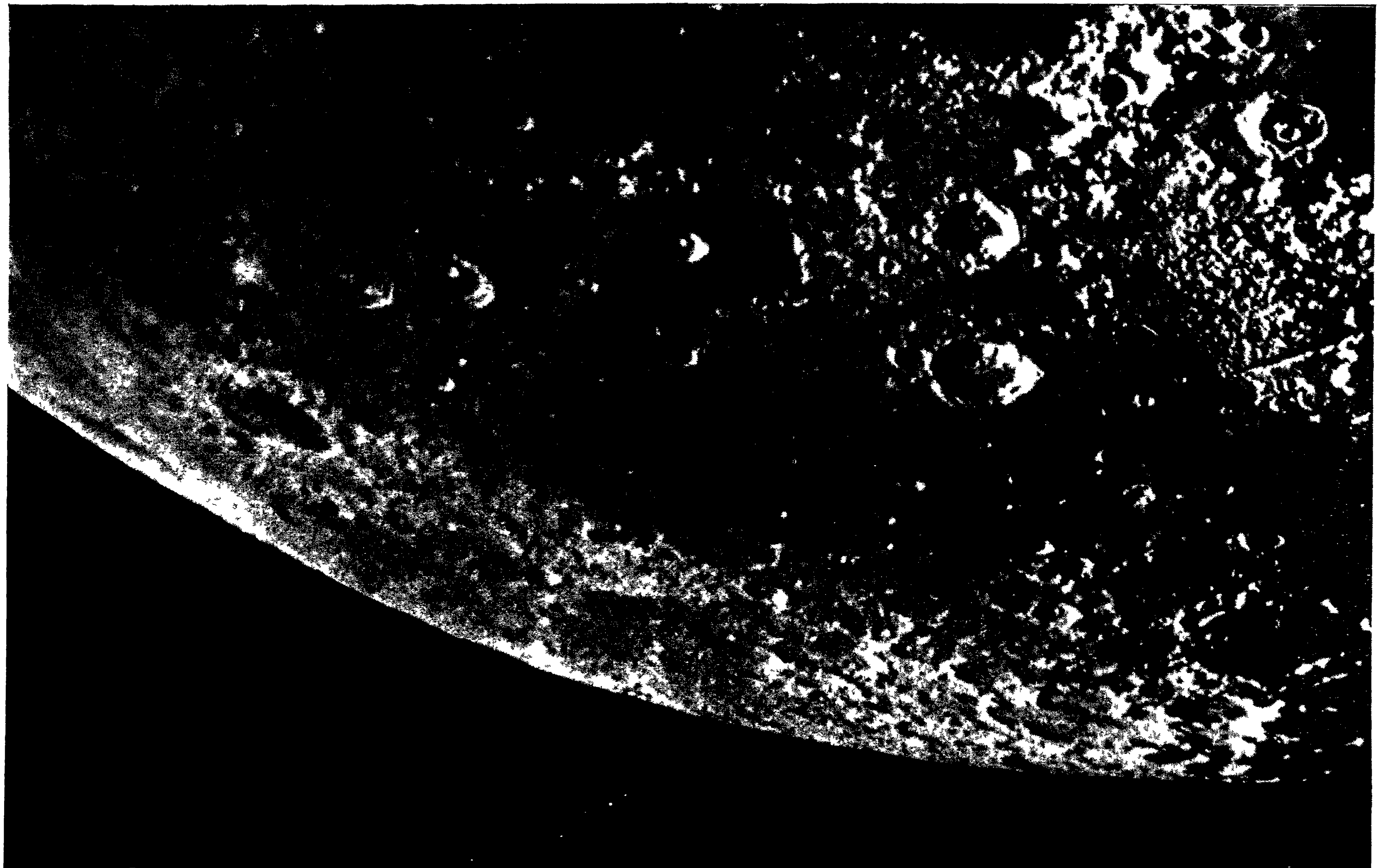
The two photographs are taken at the same time and arranged for viewing through a stereoscope When this is done the real nature of the Moon as a huge globe is strikingly brought out



From "Knowledge"] [Taken at the Paris Observatory by MM Loewy and Puiseux

A PHOTOGRAPH OF A PORTION OF THE MOON'S SURFACE

On the upper part, the Aridaeus and Hyginus Clefts are well seen They are situated not far from the centre of the disc The lower half shows a good portion of the Mare Serenitatis This is bounded on the right by the Caucasus and Alpine Ranges, the Haemus Mountains forming its upper or southern boundary The large oval ring plain near the lower left hand edge is known as Posidonius, sixty-two miles in diameter Its eastern wall has been very much reduced by the erosive influence of the lava which formed the Mare Serenitatis on the margin of which it now stands



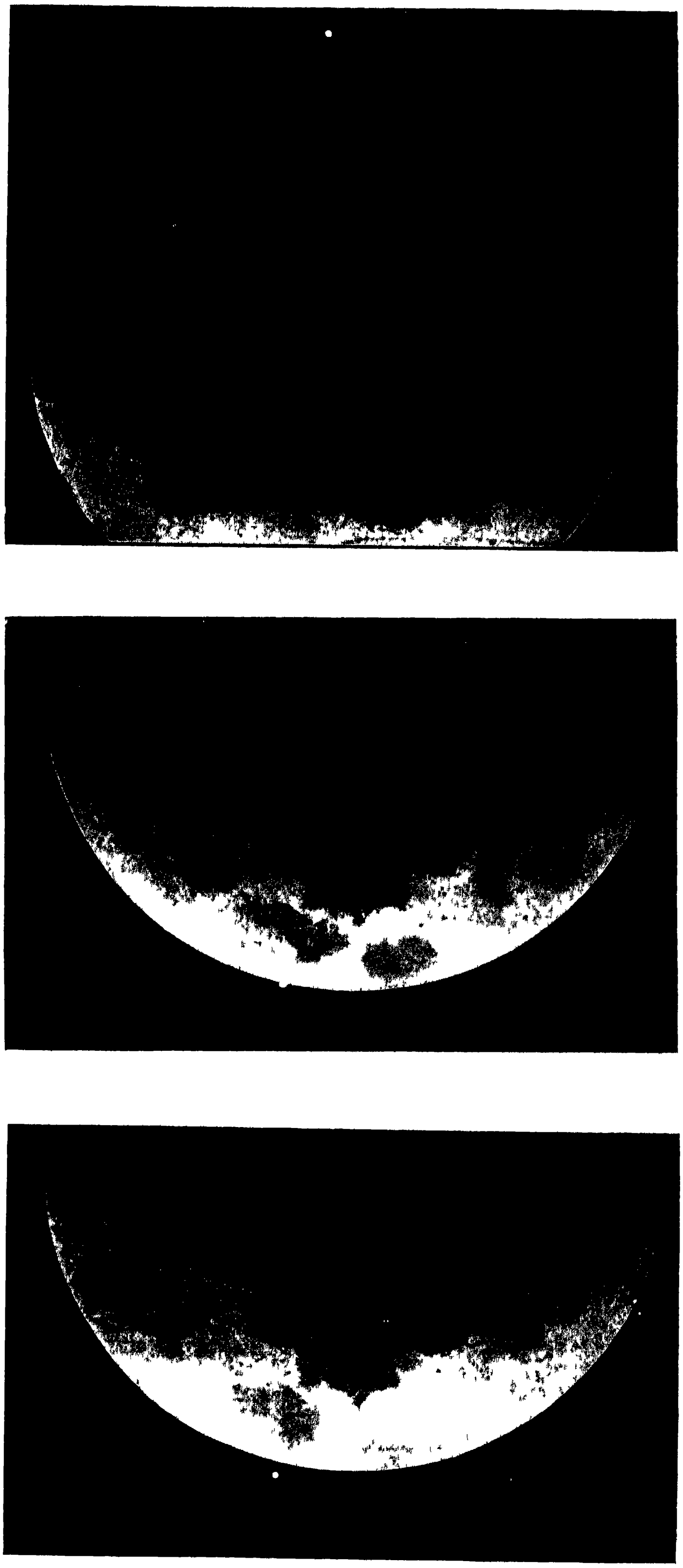
From "Knowledge"] [*Taken at the Paris Observatory by MM Loewy and Puiseux*

REGION NEAR THE MOON'S NORTH POLE

This shows the region near the north-west limb There is a curious arrangement of crater-rings in pairs, where each member is similar in character, and differing but little in size The crater rings are seen to be elliptical in shape, but they are really round, the ellipse being due to foreshortening, in consequence of the Moon being a globe The pair of rings on the left, lying endwise to each other, are Atlas and Hercules—the latter has a large crater on its interior Atlas is about fifty-five miles in diameter The two large crater rings to the right, partly filled with shadow, are Eudoxus and Aristoteles, with walls rising 12,000 to 15,000 feet above the interior

is at least 5,000 feet in altitude Copernicus has a multiple central mountain, consisting of seven peaks and already alluded to Another fine instance of a great crater ring with a central mountain is Theophilus Here again the original mountain has been shattered into several parts, one of which, according to Elger, rises to 6,000 feet above the floor, the whole mass covering an area of about 300 square miles Another prominent ring plain with a fine central mountain is Bullialdus, with its peak rising at least 3,000 feet above the interior

In contra-distinction to these and many others that might be pointed out, there are numerous instances of large mountain-enclosed plains, which show no traces of a central mountain, such, for instance, as Plato, Archimedes, and Ptolemaeus It is quite possible that central mountains once existed on these interiors, but the present appearance of the surface suggests that they have been melted down to the general level by lava when the whole interior was in a liquid state There are also other mountain-ringed enclosures where the erosive forces have not quite succeeded in destroying all traces of a central mountain mass



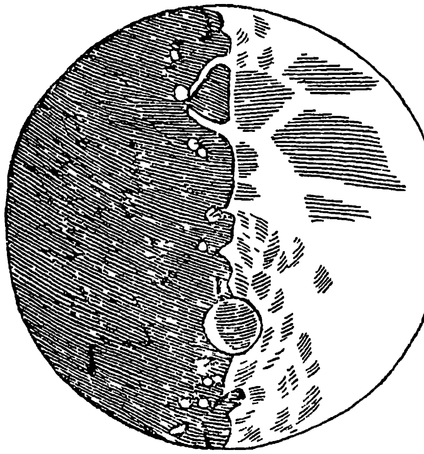
Photos by] [*Yerkes Observatory*

OCCULTATION OF A STAR BY THE MOON

Very frequently the Moon passes between us and a star, which is thereby occulted and disappears behind its disc, reappearing after an interval on the opposite side These photographs show such an event taking place in connection with the first magnitude star Aldebaran In the first photograph the star is seen close to the edge, in the second it is just in contact with the limb of the Moon, and in the third case it has just reappeared beyond the unilluminated edge By carefully noting the duration of the time the star is occulted the exact diameter of the Moon can be calculated

Instances of these are found in Pitatus, Cleomedes, Atlas, Posidonius, Gassendi, and Alphonsus. In one or two other cases the central mountain has probably given place to a crater depression. This is well illustrated by the crater ring Hesiodus.

As to the origin and nature of these mountains, there can be little doubt but that they are volcanic cones, thrown up after the interior of the ring plain on which they stand had solidified and when the volcanic energy was waning, and had arrived at a similar stage to that on the Earth, when our present volcanoes were formed.



MAP OF A PORTION OF THE MOON

This little chart is a copy of one made by Galileo in the year 1610, and is probably the very first ever made. It is very difficult to identify with certainty the formations shown with anything on the Moon at present.

The smallest elevated objects on the Moon are the *Crater Cones and Craterlets*. These are very numerous, and no attempt has been made to count them; every increase of telescopic power adds to their number. Many known now are less than half a mile in diameter. Some of the smallest of these crater cones are found in the interior of Archimedes and Plato, and form excellent telescopic tests. These minute objects strongly resemble terrestrial volcanoes.

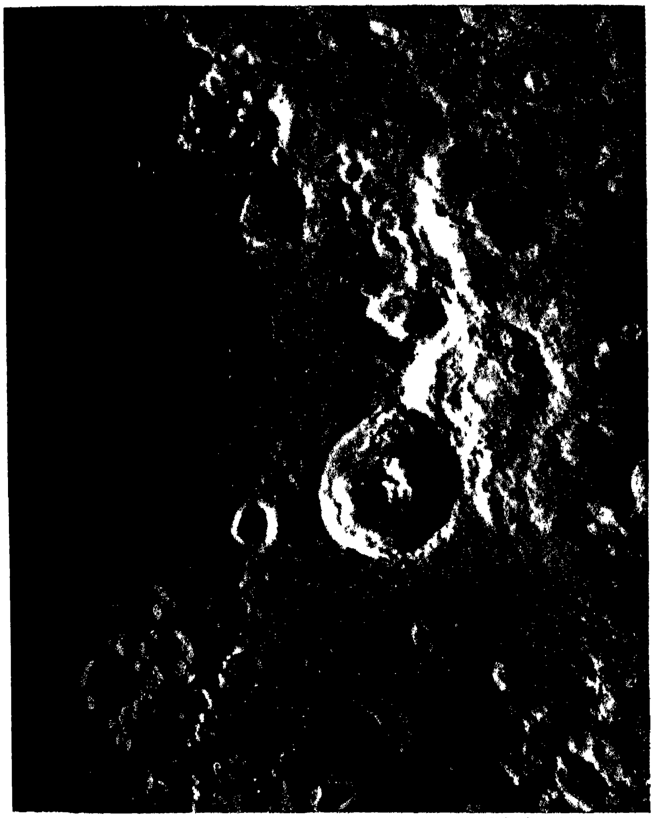


Photo by] [*Yerkes Observatory*

REGION OF THEOPHILUS

A fine photograph of the mountain ringed plain Theophilus, sixty-four miles in diameter. The central peak rises 6,000 feet, and the inner walls rise full 15,000 feet above the interior. Radiating from its outer walls lava ridges can be seen, also some minute craters in chains.

Crater-pits.—These are in a distinct class, inasmuch as they are depressions, but, like the craterlets, are found all over the Moon, though principally on the great expanses of the Maria. Some are without external walls while others have them, but in all cases they rise but a few feet above the outside level. They are best seen when near the terminator.

Among the more obscure details of the lunar surface, but of extreme interest, are the clefts or crevasses, which may be divided into two classes: the *Valleys*, and *Cracks* or *Clefts*. Of the valleys, the most important is the great Alpine Valley, some eighty-three miles in length, which cuts through the Alps to the west of Plato. It averages five or six miles in width, and is easily seen in the photographs of this region or by means of a small telescope. Other valleys of less importance and distinguished only from the clefts by their width and gently sloping sides, abound. Several examples may be given. From the east side of Hesiodus runs a long valley, almost in a straight line, for 200 miles. It is two or three miles in width at its commencement, but after some distance has been traversed

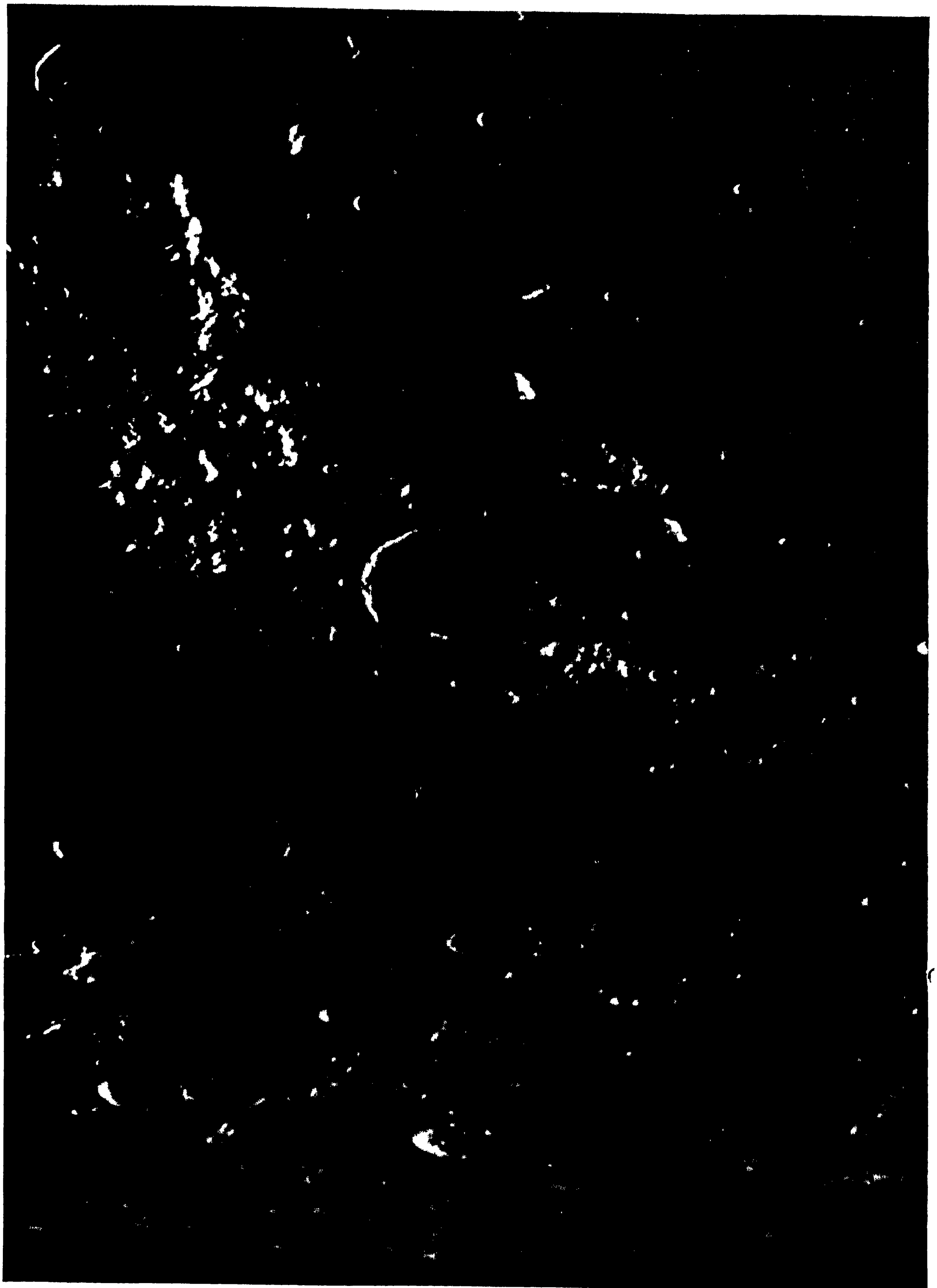


Photo by] [*Mount Wilson Observatory*

REGION OF THE LUNAR RING-PLAIN PLATO

Reproduced from a photograph taken at Mount Wilson Observatory The lower portion of the photograph shows the appearance of the surface at the north pole The crater rings are elliptical by reason of 'oreshortening, due to the Moon being a globe The large ring p'ain near the centre is known as Plato The level region below it is the Mare Frigoris, and that above is the Mare Imbrium A little above Plato are two isolated mountain masses, known as Pico and Piton The mountains on the left of Plato are the Lunar Alps with the great Alpine cutting through them

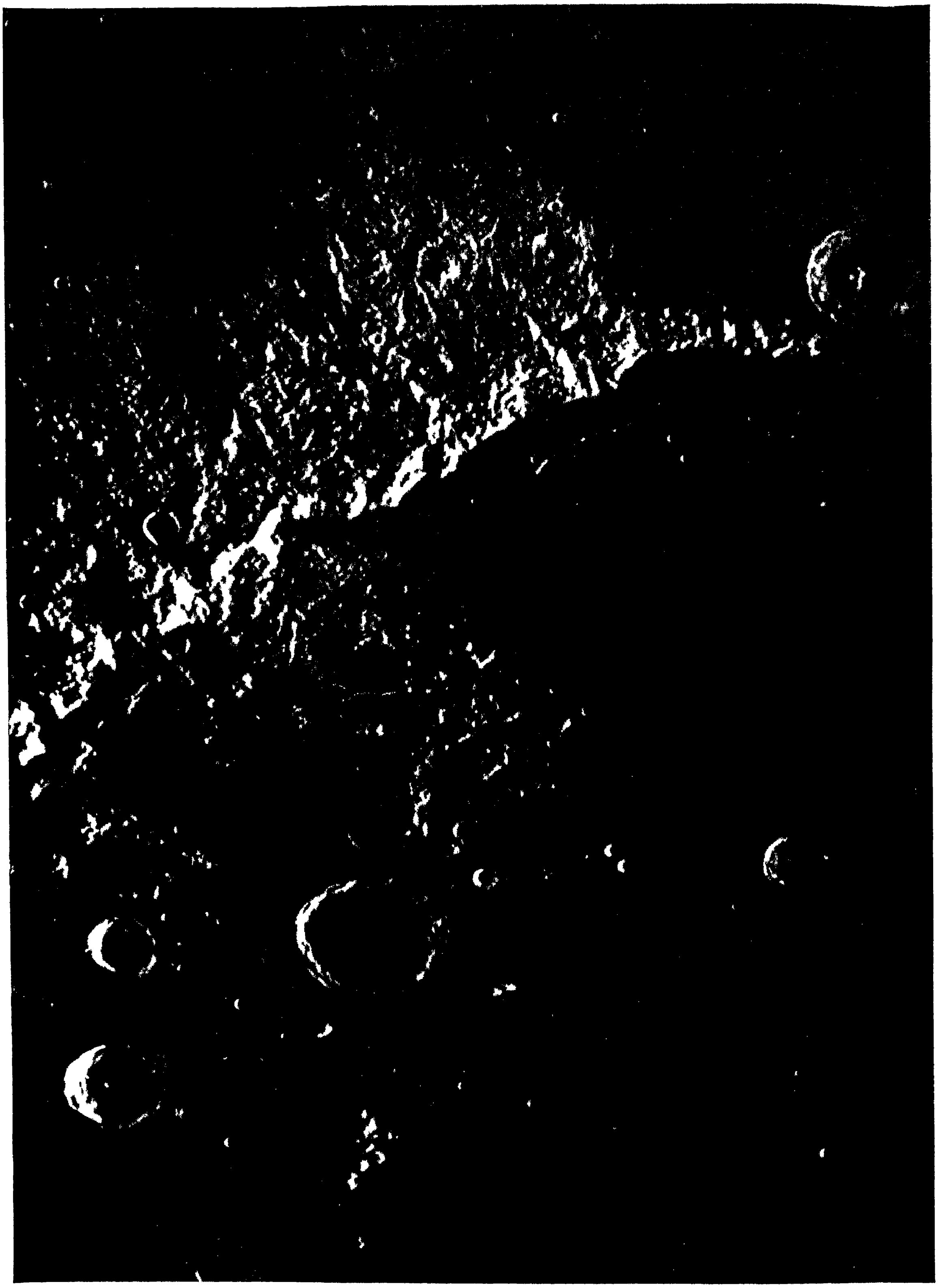


Photo by] [*Mount Wilson Observatory*

REGION OF THE LUNAR APENNINES

This is reproduced from one of the Mount Wilson photographs It gives a very fine view of the Apennine Range of Mountains which bound the Mare Imbrium and are seen at this time under the rays of the setting Sun At the end of this range—on the right—is the fine crater ring Eratosthenes Near the centre is the large mountain ringed plain Archimedes, fifty miles in diameter, with walls rising nearly 5,000 feet above the interior Running from Archimedes towards the mountains will be found a number of valleys extending for many miles

it gradually contracts and becomes increasingly difficult to trace There is also another fine specimen, which begins at the northern end of Herodotus, and runs in a horse-shoe like curve for a great distance Both these objects are easily seen under proper conditions with a small telescope On the western side of the Mare Humorum are three large and prominent curved valleys, running concentric with the shore of this sea The longest one has a course of 190 miles This group comprises the most remarkable and finest system of valleys on the Moon

Clefts —The true clefts, of which there are several hundred already known, are in the nature of cracks or crevasses Some are of considerable size and quite conspicuous, whilst others are so narrow that they test the defining power of our best telescopes These cracks differ from the valleys in that their sides are very jagged, and frequently disturbed by the intrusion of craterlets along their course, and are probably caused by the once plastic surface contracting during the period when it was becoming solidified Most of these clefts are found in the northern hemisphere, where the Maria and other level surfaces abound, they are quite absent from the mountainous regions of the south Many of the ring plains are traversed by them Fine systems of clefts will be found on the interior of Atlas, Posidonius, and Gassendi, whilst on the interior of Alphonsus several of these are found to be associated with the well-known dark areas in that crater, from which they issue like dried-up river-beds Again, on the open plain to the west of Triesnecker is found a very complex system of clefts of considerable length, all apparently having their source in one common centre Quite close to these, and in some respects physically connected, are the great Hyginus cleft and the long valley-like depression, known as the Ariadaeus cleft, but having all the characteristics of a shallow valley

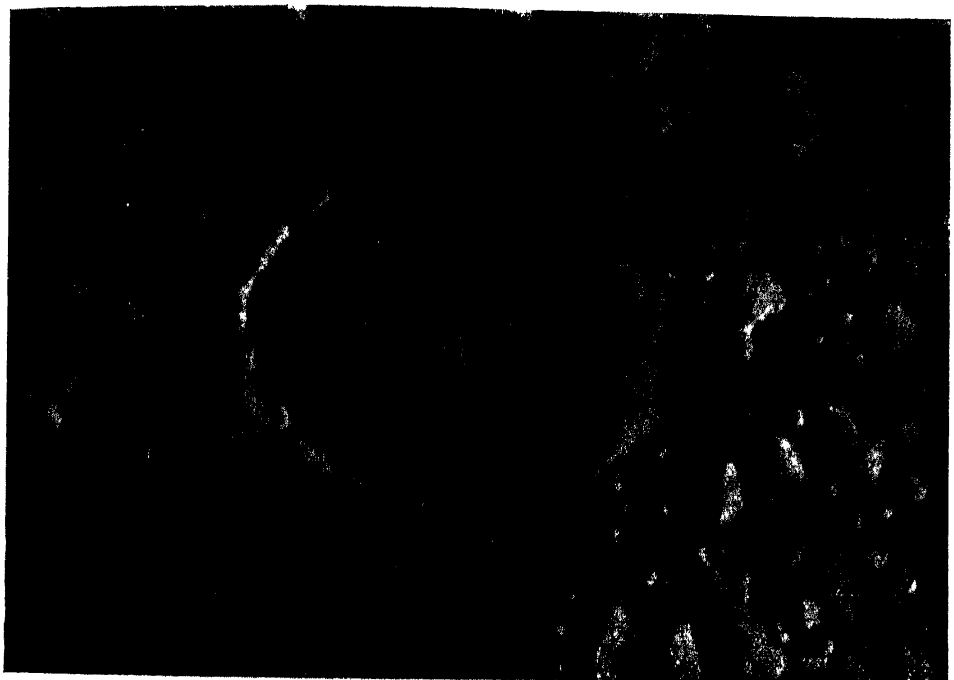


Photo by permission of] [*The Yerkes Observatory*

THE LUNAR CRATER RING TYCHO

This photograph gives a good general view of this noble object, fifty-four miles in diameter, and with ramparts rising steeply from the interior to the height of 16,000 feet In the centre is seen a large mountain mass, casting its shadow for some miles on the plain at its feet This crater is the centre of the greatest system of bright rays on the Moon The shape of Tycho is circular, the elliptical appearance being due to foreshortening, because the Moon is a globe

A description of the Moon's surface would not be in any sense complete unless some reference were made to three other classes of formation These are the mountain ranges, the isolated peaks, and the wonderful systems of bright streaks or rays which are so conspicuous on the Full Moon's face.

Mountain Ranges, etc —The most striking feature presented by the Moon when viewed through a good telescope is the extremely rugged and mountainous character of much of its surface, all of which indicates that at some time or other it must have been the scene of the most appalling disturbance or upheaval The mountains of the Moon lose nothing in comparison with those of the Earth on the score of size and height Reliable measures of these mountains show peaks rising to 25,000 or 26,000 feet The surface to the south, whilst very rugged and broken by all kinds of crater-like formations, possesses no well-defined mountain ranges These are however found in the northern hemisphere There they are seen to form the boundaries of some of the large Maria or seas The principal ranges are the Alps, the Caucasus, and the Apennines They form a massive range of peaks bordering the western side of the Mare Imbrium, and separating it from the Mare Serenitatis

These names were given by old astronomers from some fancied resemblance to their terrestrial namesakes They even went so far as to name one of the peaks in the Lunar Alps Mont Blanc, which rises some 12,000 feet above the plain at its base Many other peaks in the same range rise from 5,000 to 8,000 feet The massive Caucasus range, though not so high as the Alps, boasts one peak near the ring plain Calippus, which towers to the height of 19,000 feet The Apennines, however, are the most important mountain range on the Moon It extends in an enormous curve some 400 miles, terminating on the south-east at the fine ring plain Eratosthenes, where the massive Mount Wolf is found rising about 12,000 feet There are upwards of 3,000 well-defined peaks in this range of mountains Other mountain ranges, of which space will not allow any description, are the Taurus Mountains, the Harbinger Mountains, the Altai Mountains, and the Riphaean range Other ranges are situated

Photo by] [*Yerkes Observatory*

THE MARE SERENITATIS

The photograph shows the whole of the Mare Serenitatis, with the crater Bessel near the upper part On the upper edge is the large crater ring Plinius, and from this running all down the left side is a curious serpentine ridge Other ridges of a similar nature are found in many places on the Moon, but mostly on the surface of the "seas"

Painting] [By Arthur Twidle

THE MOON'S HALO

An effect produced by innumerable prism shaped crystals of ice suspended in the atmosphere and distant forty-five times the diameter of the Moon's disc from the outer edge of the Moon The *halo*, or glory, has prismatic colourings, the red tint at the edge nearest the Moon and the blue on the outer margin This distinguishes the phenomenon from the more usual *corona*, which is due to aqueous vapour and is coloured blue nearest the luminary and red towards the exter or rim

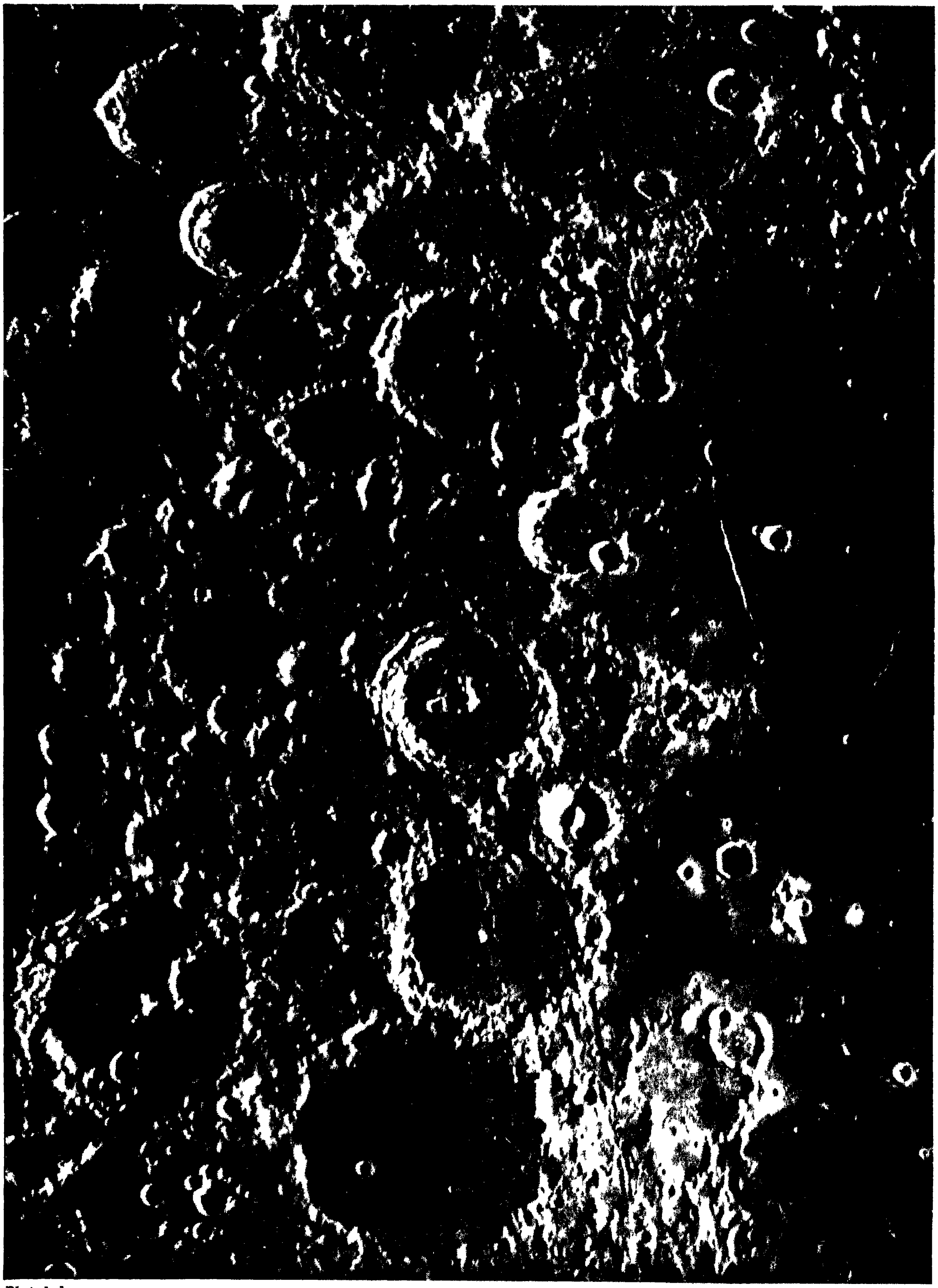


Photo by] [*Mount Wilson Observatory*

REGION NEAR THE CENTRE OF THE MOON

This is another reproduction of one of the latest photographs taken at Mount Wilson Observatory, and shows a wonderful amount of fine detail A number of curious longitudinal valleys will be seen cutting through mountainous districts The large ring plain at the bottom is Pto emaeus, and above this Alphonsus and Arzachel, and to the left of these objects the rugged nature of the surface, as seen under the rays of the setting Sun, is well brought out The " Straight Wall " will be noticed at the upper right-hand side, and a little farther to the right of this is a long valley running parallel with it

so near the edge of the Moon that their peaks are often seen in profile against the sky, and when thus observed present a most charming and interesting spectacle

Isolated Mountains —There are many instances of isolated mountain masses to be found on the surface, more especially on the Maria, where they seem to have survived the levelling action of the molten lava which surged around them One well-known peak is Pico, which will be found on the open plain to the south of Plato There are several other objects of this class close by When seen under oblique illumination they are very striking objects, their white surfaces showing up in strong contrast to the long spire-like black shadows they cast on the level country at their base

The Bright Streaks or Rays —These are very conspicuous under a high light at or near the time of Full Moon They are generally associated with some large crater ring, from which they radiate in all directions to great distances Their nature and origin have never been satisfactorily explained, and at present they form one of the unsolved enigmas of the Moon So complex are they in form and so indefinite in outline that no one has attempted the almost impossible task of mapping them We have therefore to rely exclusively on photographic pictures to show the true aspect of these The most prominent of these systems of bright rays is that which is associated with the deep well-formed crater Tycho, found in the mountainous district towards the south pole, easily visible on the photographs as well as in the smallest of telescopes These rays do not radiate from the centre of Tycho, but from a spot a little to the east of it They can be traced for several hundreds of miles, passing over mountain and plain without interruption

From a Drawing] [*By the Abbe Moreux*

A CLEFT IN THE MOON'S SURFACE NEAR HYGINUS

The Hyginus Cleft is a wide rugged valley near the Moon's centre, and is seen on many photographs, also being visible in a small telescope It is probably volcanic in its origin and its course in some places seems to be interrupted by small craters Its depth is unknown

Other systems of less importance, but almost as conspicuous, are found associated with the craters Copernicus, Kepler, Anaxagoras, Aristarchus, and several others, whilst minor systems are to be seen in connection with the following crater rings Autolycus, Aristillus, Proclus, Furnerius, and Menelaus

Several theories have been put forward to explain the nature of these markings, but one and all are open to serious objection Obviously they are in the nature of superficial markings, as no elevations are found to follow their tracks across the level plains The most probable explanation is that they mark the course of cracks in the surface from which whitish material has been ejected and deposited along each side In many cases little bright craters are found on these streaks, which seems to lend some weight to the eruptive theory Another ingenious theory has been propounded by Mr H G Tomkins, F R A S , in which he suggests that these streaks are

actually deposits of salt left by the ancient oceans He has found large tracks in Northern India, where salt has been exuded from the subsoil, and becomes visible in the dry season as white streaks extending for long distances

Having thus briefly and incompletely described the principal objects found on the Moon, it will be interesting to try and ascertain what is the probable cause or causes which have produced the aspect which this surface presents Generally speaking two theories are held to explain things as they are at present The one ascribes the origin of the lunar formations to volcanic energy acting from within, and the other to forces external to the Moon, or, in other words, to the impacts of foreign bodies on its surface

The former view is the one held by the majority of astronomers, and especially by those who have made a study of the Moon's surface by means of adequate telescopic aid The minority hold to the impact theory R A Proctor once held this view, but in his later days disowned it Professor Shaler, the distinguished American geologist, held similar opinions in a modified form, and he believed that the lunar Maria, great and small, were the result of the impacts of bolides ten to fifteen miles in diameter The latest advocate of note is Dr See, an American astronomer, who holds the same views regarding the formation of the lunar seas as enunciated by Shaler Dr See is also a firm believer in the "capture" theory, which accounts for the growth of the planetary bodies by their capture of vast quantities of meteorites or small planetary bodies moving in space, and he regards the Moon as a planet which has grown to its present size by the constant rain of meteors, both great and small, on its surface

MAP OF THE MOON BY DE RHEITA

De Rheita was one of the earliest of the selenographers, and this map—made in 1645—shows what he was able to distinguish on the Moon with his poor telescope The crater at the upper part of the disc is no doubt Tycho, and from which he draws a number of radiating bright streaks He also shows very well the various Maria, or seas, and the craters Copernicus and Kepler, with their surrounding bright areas

There are many and serious objections to this impact theory which space does not allow to be fully discussed here Only a brief allusion to some can therefore be made We find on the Moon, as already stated, plains surrounded by mountain rings of all sizes up to 150 miles in diameter Judging from appearances the large rings are amongst the oldest formations, the smaller and more regularly circular objects having appeared at a later date, and probably the smaller the crater the later has been the date of its birth If we accept the impact theory we must assume, which is very unlikely, that the largest

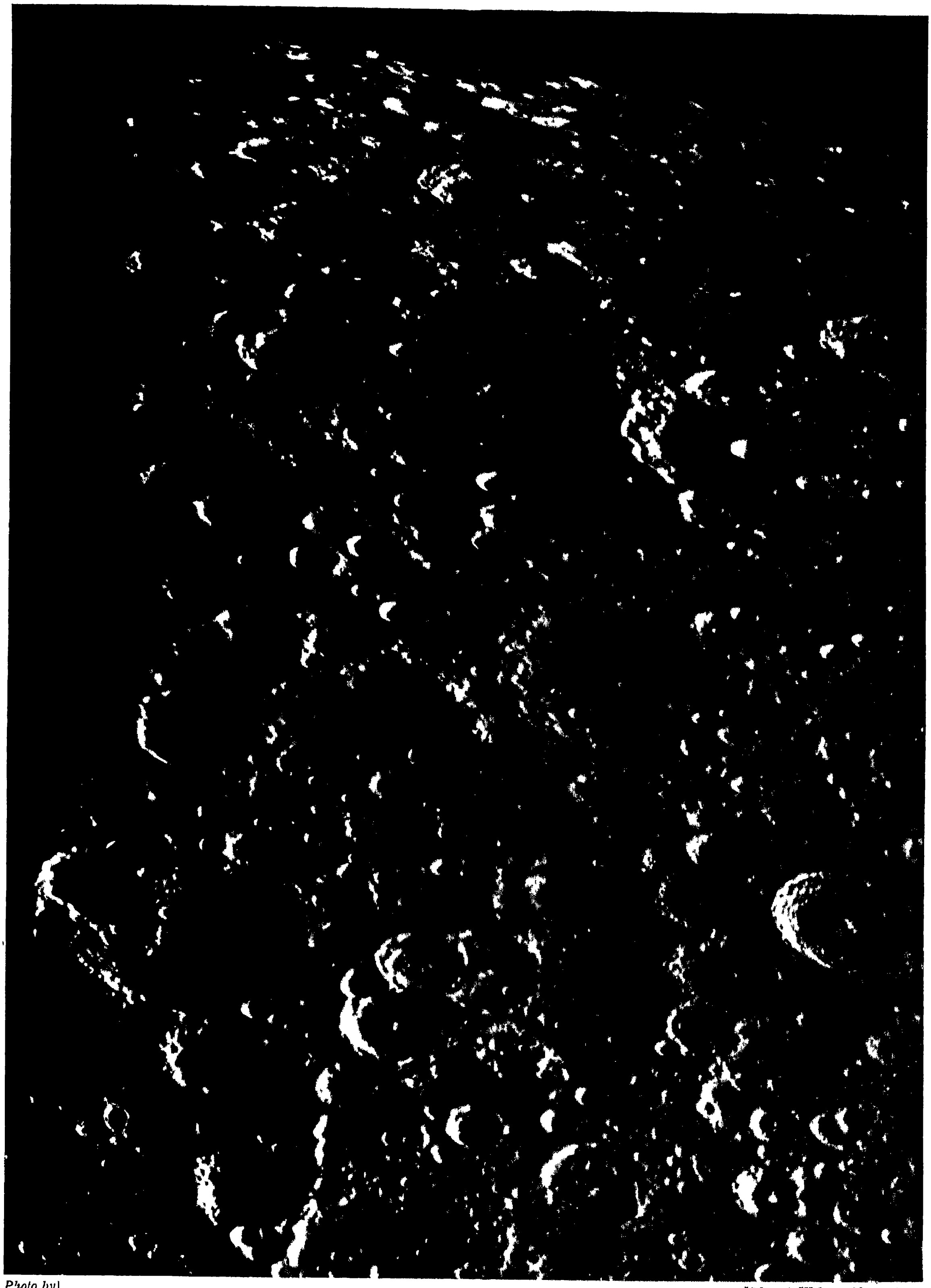


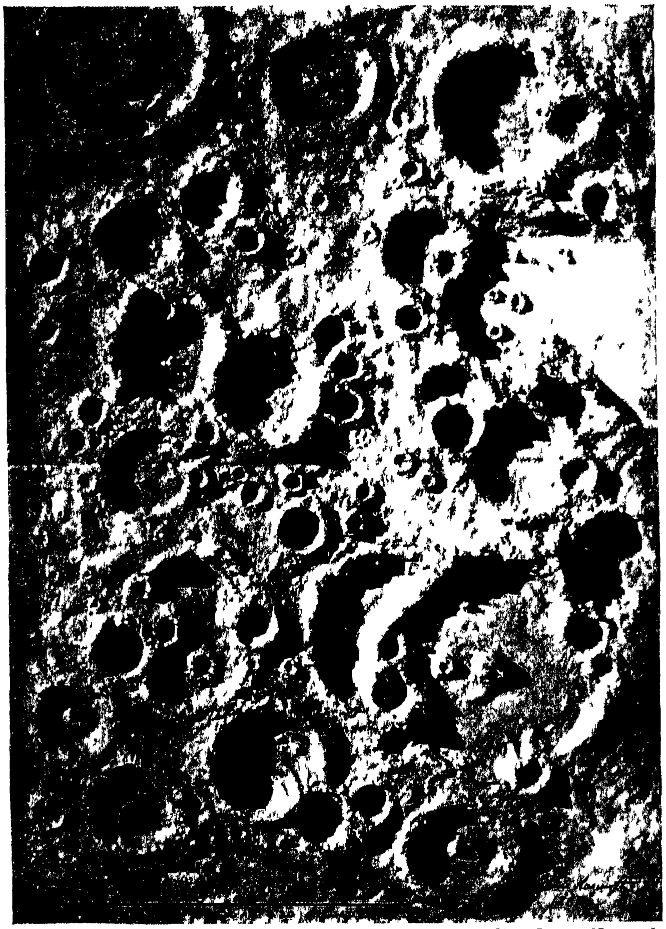
Photo by] [*Mount Wilson Observatory*

REGION NEAR THE MOON'S SOUTH POLE

This is reproduced from one of the magnificent lunar photographs taken at Mount Wilson, in California, by the use of the great Hooker Telescope of 100 inches diameter, and shows more fine detail than any other photograph yet secured The upper part extends to the south pole The surface will be found to be pitted all over with small craterlets from half a mile in diameter and upwards The Sun is setting on the extreme left of the picture and already many of the rings are filled with the shadow of night

bodies fell on the Moon in its earliest days, and they were followed later by smaller and still smaller bodies in greatly increasing numbers, until the time arrived when the supply was exhausted

Again, as already pointed out, craters are often found in pairs very much alike in all respects To account for these by the impact theory, we shall have to assume that these impacting bodies travelled in pairs with equal dimensions, which again is very unlikely A third objection is seen in the fact that we find on the Moon craterlets in rows, with their rims in contact or confluent, also many of these "crater chains," as they are termed, run in curves or segments of circles, and it is almost impossible to conceive that the impacting bodies should be endued with the power of arranging themselves in this manner



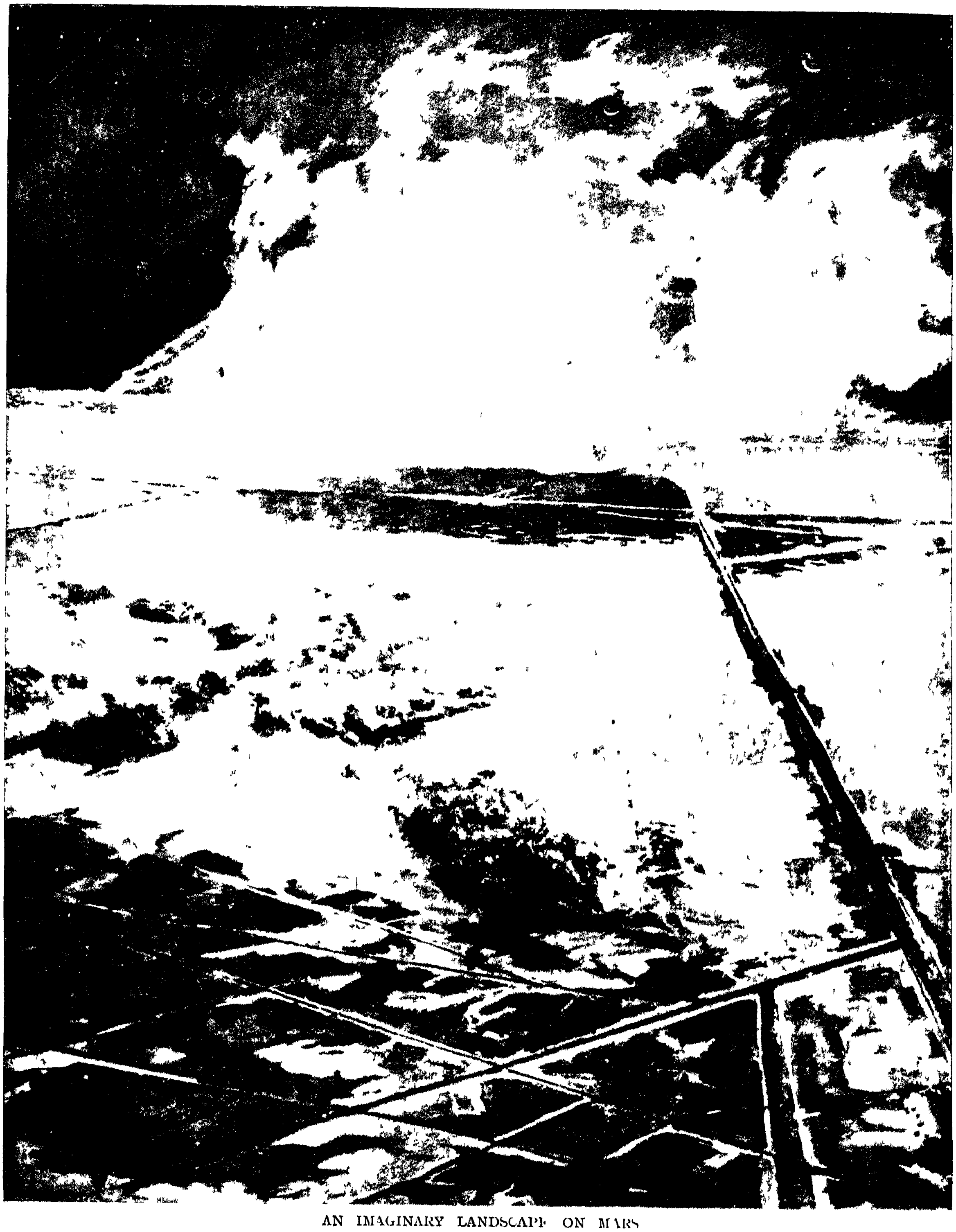
From a Model] [*By James Nasmyth*

THE MOON'S SURFACE MODELLED

Nasmyth made a careful study of the Moon's surface by means of a powerful telescope He made models in plaster of many of the lunar formations and the above is a good example of his work It gives a very realistic idea of what is seen in the telescope These models were then photographed under oblique light

On the other hand, volcanic force seems quite capable of forming the crater rings, both large and small, whilst the seas and large walled plains may have been formed by the subsidences of the Moon's surface, caused by the cooling and contraction of its crust If the Moon's crust in places was fractured by contraction the molten material below would well up through such openings and spread out on all sides, melting down the rugged surface in every direction, and continue to do so until its energy was dissipated by cooling, then the levelled surface would become firm and assume its present terminal appearance Some of the large crater rings, from their massive proportions, seem to have been able to withstand this melting power, and of these notable examples are found in the case of Copernicus, Bullialdus, Aristillus, Gassendi, Petavius, and Archimedes, but in respect of the last three named it is obvious that the height of their original ramparts has been much diminished by erosive forces

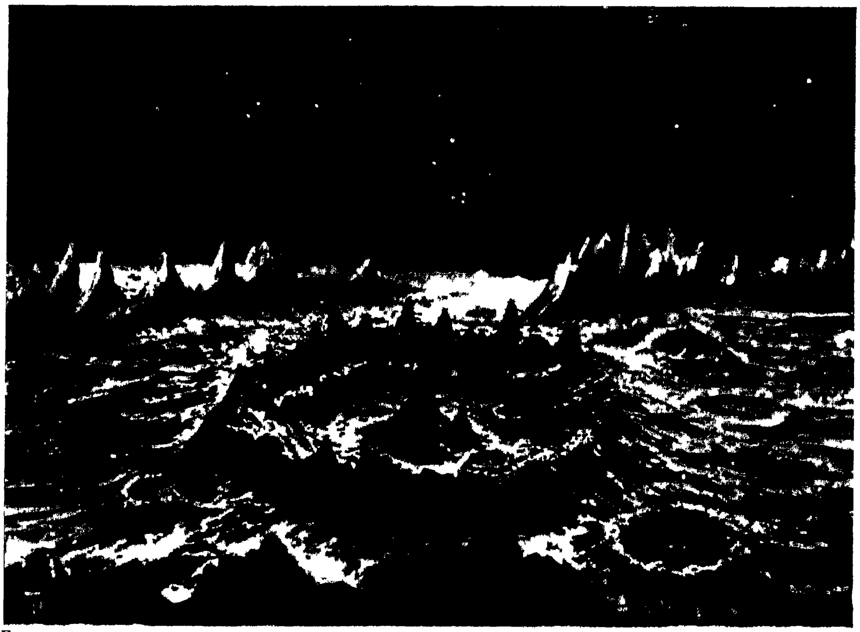
It has been urged that some of the mountain-ringed plains are too large to have been formed by volcanic agency, but we must not lose sight in this connection of the fact that the force of gravity on the Moon is only one-sixth of the same force on the Earth, and assuming the eruptive power to be the same in both cases, it seems quite reasonable to expect craters on the Moon to be six times as large as on the Earth, where even craters of twenty miles in diameter are known to exist Further, it must be borne in mind that the surface rocks on the Moon are probably of much lighter material than those on the Earth A large crater is said to exist in the Island of Mauritius, about twenty miles in diameter, and there is another in Central Africa, recently explored, measuring about ten miles in diameter, surrounded by cliffs rising to 1,000 feet



AN IMAGINARY LANDSCAPE ON MARS

Three-fifths of Mars' surface is covered by bright orange regions probably deserts of red sand. The remaining two-fifths are occupied by dusky green regions usually believed to be vegetation. The only water on Mars is probably that surrounding the melting snows at the poles. Some astronomers believe that the straight dark streaks crossing both dark and bright areas are artificial canals built for the purpose of making the best use of this scanty water supply. They do not consider that we see the canals themselves but rather the vegetation growing upon their banks when the water from the poles is filling them. In addition to these things this picture illustrates a sandstorm—a phenomenon believed to be common on the planet. It would however appear more plausible that if there *are* canals they would consist of some form of pipe system, otherwise we cannot well explain how the water flows across the planet or why it does not immediately evaporate owing to the rareness of the atmosphere of Mars.

The present condition of the Moon's surface.—Upon this matter various views are held, for the support of which plausible reasons are given. The difficulty in settling this point is our inability to reproduce in our laboratory experiments the exact conditions which exist on the Moon. It has been assumed for many years past that the Moon possesses neither atmosphere nor water, and in consequence is unsuitable for the existence of animated life, and further, is not subject to such physical changes as are in constant operation on the Earth. In fact, it is assumed that the Moon's surface has arrived at its terminal condition, and there is nothing more to be learned from it. These widely held opinions have led professional astronomers to discontinue their observations of this body, and to direct their attention to other branches of Astronomy which promise better and more immediate results. This field has consequently been left open for amateur observers for a long time past. The opinion that the Moon has no atmosphere has in recent years had to be somewhat modified or abandoned, and if certain appearances which have been seen are rightly interpreted they show that after all some kind of atmosphere exists, though admittedly of great tenuity. The best test for the existence of an atmosphere is to note whether stars which are occulted by the Moon show any tendency through refraction to remain visible for a few seconds longer than they should do if they had no atmosphere to traverse, before being blotted out by the solid body of the Moon passing in front of them.



From a Drawing] [*By the Abbé Moreux*

PERSPECTIVE VIEW OF A LUNAR MOUNTAIN RING

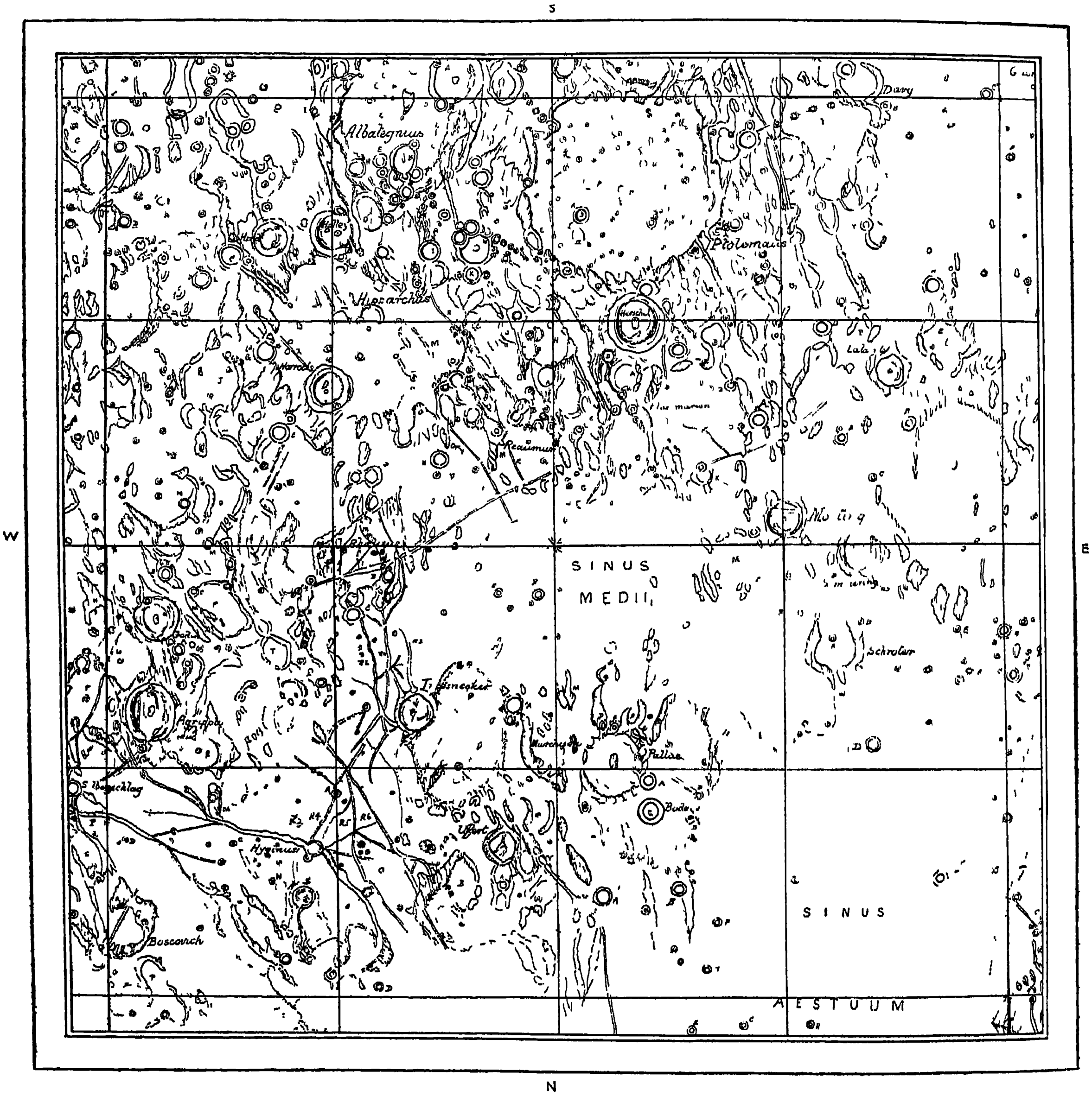
This gives a realistic view of the rough surface of many parts of the Moon's surface. In the foreground is a crater ring, showing peaks on its wall, and a central mountain cone. The wall is in parts double—the result of landslips—and this feature is a very common one in connection with the lunar craters.

Generally stars when occulted disappear instantaneously, but there are many instances on record where the light of the star has faded out gradually. But this behaviour of the star would be the same if it passed along some valley between the mountains which were in profile on the limb. There are also many records of local obscurations of portions of the surface which cannot be explained unless we assume the existence of low lying vapour or mist. Various estimates as to the density of the lunar atmosphere have been made, deduced from observed facts. Neison's estimate is that it is 300 times less dense than the Earth's atmosphere, whilst Professor W. H. Pickering arrives at the conclusion that the Moon's atmosphere is only equal in density to that of the Earth's at an elevation of forty-five miles.

As regards the existence of water, this has been denied, and some hold that the Moon never possessed any, and further, that the evidences of erosion are only due to the flow of lava. Professor Pickering, on the other hand, considers he has found evidence that the Moon once possessed water, though in small quantities. He thinks that during the eruptive period of its history vast quantities of water in the form of hot springs and geysers were expelled, and he has found what he terms river-beds, in which this water was carried away from its source.

If the Moon ever possessed large quantities of water what has become of it? Neison, in answer to this, suggests that it has been withdrawn into the interior through faults and cracks in the surface If so, this would account for the occasional local obscurations, which suggest that water vapour in small quantities still exists

Changes in temperature —Does the Moon get very hot during the long exposure to the Sun's rays, for a period equal to fourteen of our days in each month, and conversely, does it get very cold during the equally long period of darkness? Opinions on these two points differ greatly Some suggest that radiation from its surface is so rapid that it does not actually get warm, and others say that the

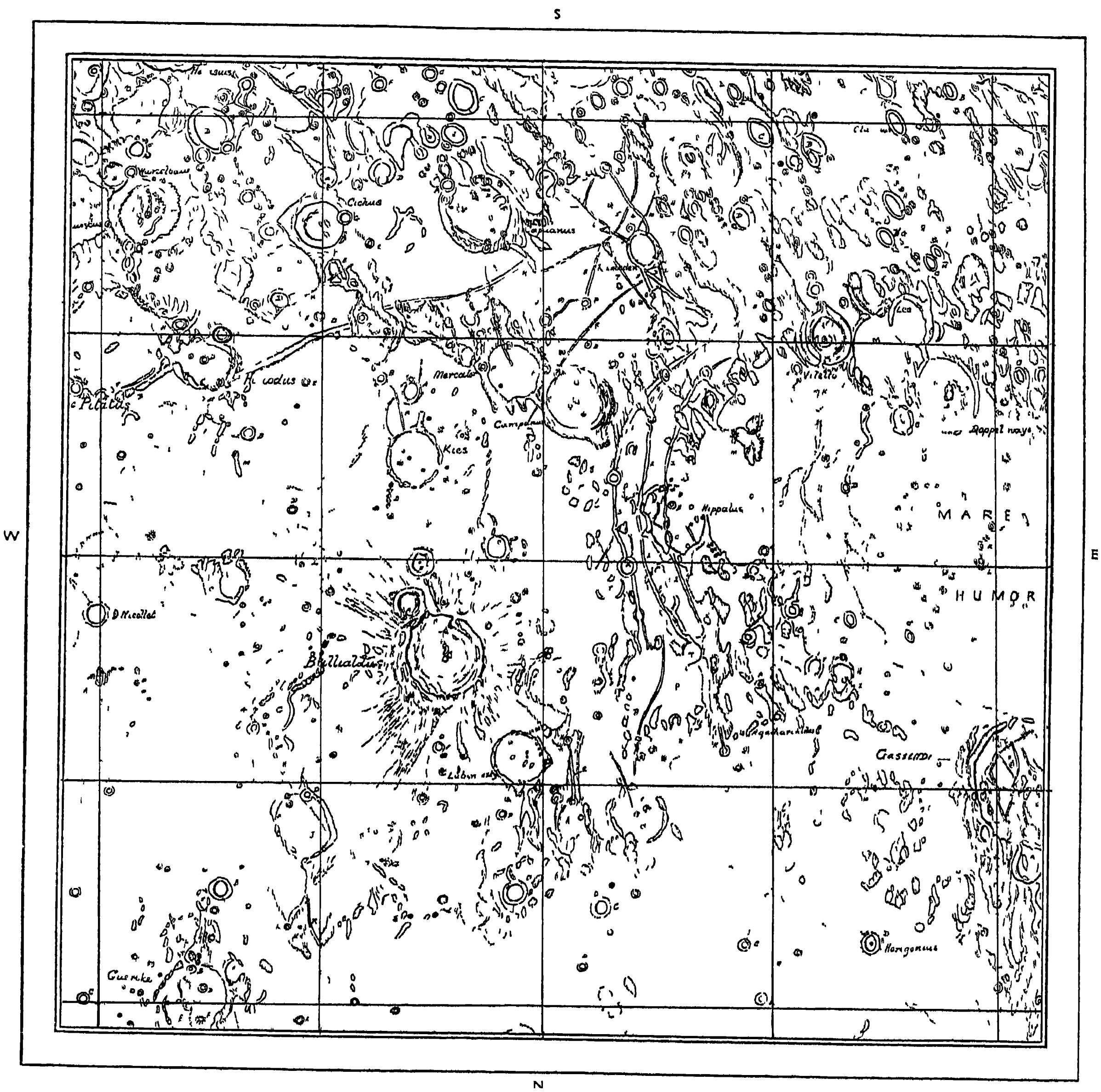


MAP OF THE MOON

This is a copy of one of the sections (No 1) of a large map of the Moon, drawn by the writer, reduced to about one-third of the size of the original It includes a region round the centre of the disc It shows several of the objects referred to in the text, notably the system of clefts west of Triesnecker—the Hyginus Cleft and the large mountain-ringed plain Ptolemaeus The scale is about eighty miles to one inch

surface is constantly ice-bound. Nearly all are agreed, however, that the cold of the Moon's long night must reduce the surface temperature to that which exists in space and about which we have no certain knowledge.

Professor Very has for many years given attention to the question of the day temperature on the Moon, and by the use of a greatly improved bolometer has recently arrived at the conclusion that not until the Sun has reached an altitude of fifteen degrees in the Moon sky does the temperature rise above freezing point, then as the Sun rises higher, the temperature rises until at the time it is overhead the rocky surface has become as hot as boiling water, whilst towards the end of the second week the



MAP OF THE MOON

This is Section 7 of the large map of the Moon, drawn by the writer, reduced to about one third of the size of the original. It covers a district to south-east of the centre, and shows among other interesting objects the long curved valleys on the west side of the M. Humorum, the Hesiodus Valley, and the large crater ring Bullialdus, to all of which reference is made in the text. The scale is about eighty miles to one inch.

temperature of the surface rises to about 356° Fahr The rocks of course retain their heat far into the afternoon, after which the temperature falls very rapidly, and before the Sun sets frost prevails, and would show itself in the form of hoar frost if any water vapour exists

Changes on the Moon—If we had photographs of the Moon or very accurate charts made some hundreds of years ago, and could compare them with those we now possess, a satisfactory answer might be possible Unfortunately we do not possess this old material, but we are doing our best to lay up accurate records for the future, notwithstanding the prevalent opinion that no change is shown Several instances of change are alleged to have occurred, but the weight of evidence adduced after the most careful consideration seems to be against this view, and the most probable explanation is that in the instances examined the differences shown are due to some error in drawing or description by the old observers At the same time changes must be going on if the surface is subject to the great variations in temperature already alluded to, but these are probably on such a small scale, such as the result of landslips or new fissures caused by the secular cooling and contraction of its surface and similar incidents, as to be beyond the reach of our telescopes Should however a large change take place, caused by subsidence of the surface over a considerable area, or the collapse of some crater ring, or the appearance of a new crater of any size, on a well-mapped part of the Moon, it would be discovered in a short time

MOUNTAIN-RINGED PLAIN

This is a drawing of the mountain-ringed plain Gassendi, by Mr J W Durrad, F R A S It shows the remarkable system of cracks on the interior, and the multiple central mountain Gassendi is fifty-five miles in diameter

Vegetation on the Moon—Before closing this description of our Moon's surface some reference must be made to the researches of Professor W H Pickering, in which he claims as the result of his observations made in Jamaica under the best seeing conditions, that he has discovered certain seasonal changes in respect to portions of the surface which can only be satisfactorily explained on the assumption that they indicate the growth of some sort of vegetation He found in the case of Aristillus and in other places as well, that as the Sun rose certain dark surface markings gradually developed, and pursued a systematic change in form and size as the lunar day progressed These dark areas could not be shadows as the Sun's rays were overhead, or nearly so, and he thinks that the vegetation passes through all the stages of what we know as spring, summer, and autumn, during the fourteen

days when the surface is exposed to the continuous influence of the Sun's rays. Other astronomers, mostly amateurs, are now directing their attention to these and similar instances of seasonal change, with the hope that evidence will accumulate to test the soundness of the Professor's views. In the foregoing pages it will be gathered that whilst in the aggregate our present knowledge of the Moon and its surface conditions is fairly complete, the result of so much strenuous and persistent work spread over the last 100 years, in which the work of amateur astronomers forms the larger part, there still remain many enigmas which we can only hope will be solved by the continued efforts of the lunar observers of the present and future generations.

From a Drawing] [*By the Abbé Moreux*

THE "STRAIGHT WALL," ON THE MOON

This unique and remarkable formation is shown in a realistic way by the artist. It is a vertical escarpment or range of cliffs about 500 feet high, running along the edge of a gigantic fault in the surface. At its foot a deep ravine has been suspected.

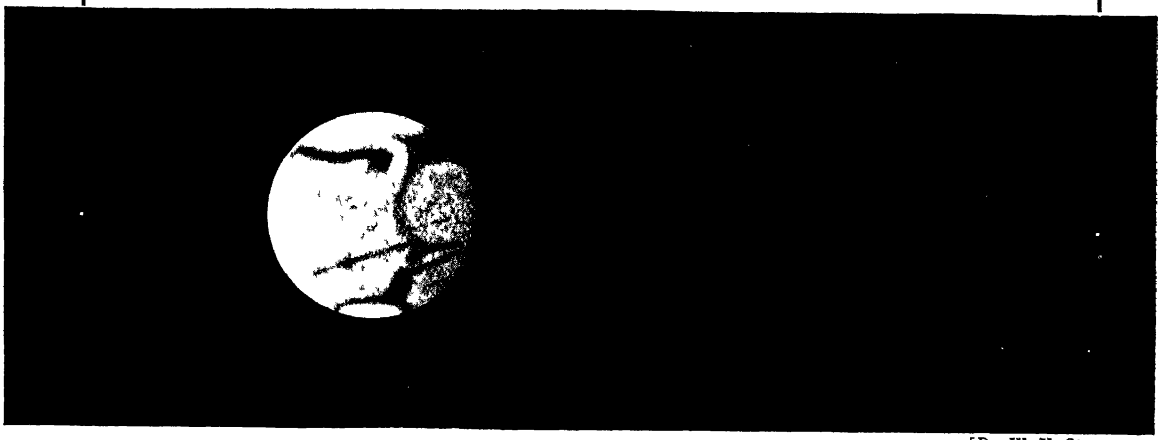
CHAPTER VII.

MARS

By R. L. Waterfield, F.R.A.S.

FOR a few months every two years a brilliant orange-red star makes its appearance in our skies. It is the planet Mars, the one world whereon we find conditions comparable to those on Earth. There we have discovered much that is akin to this world; perhaps also we have found indications of something akin even to ourselves.

Mars is the nearest planet outside the orbit of the Earth. We do not, however, approach so close to it as we do to Venus, yet we can see a great deal more upon its surface owing to the clearness of its atmosphere. Mars moves round the Sun in a somewhat elongated orbit, its distance from it varying from 130 million miles to 155 million miles. The Earth's orbit is elongated to a smaller extent, but the *direction* of its elongation is not the same. The two orbits, therefore, lie closer together in some places than in others; their smallest separation is 35 million miles, their greatest 65 million miles. To make a complete journey round the Sun, Mars takes 687 of our days, so that his *year* is nearly twice as long as our own. This will mean that the Earth must overtake and pass comparatively close to Mars at

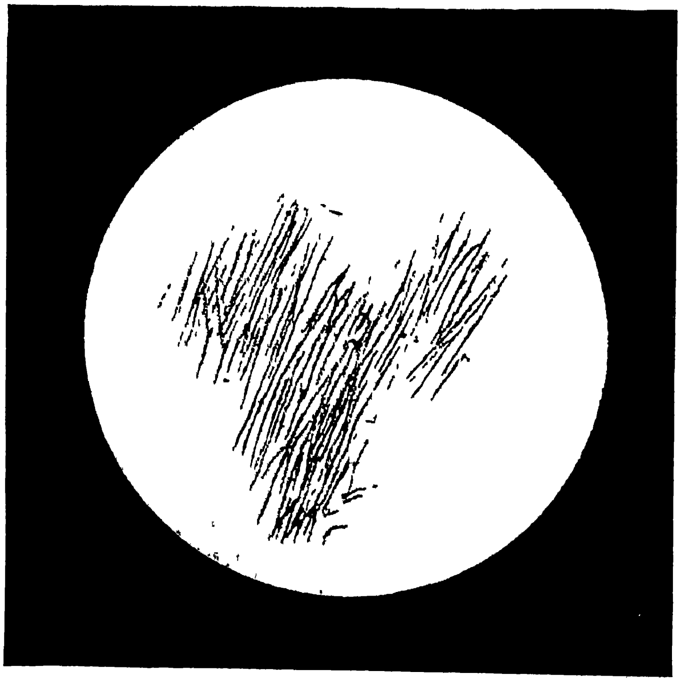


[Dr W H Steavenson

MARS AND ITS MOONS

Two moons, each less than ten miles in diameter, move round Mars The picture illustrates their relative distances from Mars' surface The time taken by the nearer one, *Phobos*, to move round Mars (the Martian month) is shorter than the Martian day!

intervals of about two years and two months The diagram, page 297, shows that at these times of passing the two planets are nearer together than at others, Mars being then in the opposite part of the sky to the Sun rising at sunset and reaching its highest in the sky at midnight These occasions are called *oppositions* Since they occur every two years and two months, an opposition in August will be followed two years later by one in October We see from the diagram that the closest oppositions are those occurring nearest to August 25, and the most distant those nearest to February 25 For seven and a half years following the best opposition each succeeding one will be less favourable, after that they will improve, and another close opposition will occur after a complete cycle of fifteen years During the last fifteen years the most favourable opposition was that of 1909 The next, in 1924, will be even closer, one of the closest of the century



FIRST DRAWING OF MARS—HUYGHENS

This drawing was made at 7 p m November 28, 1659 It shows the *Syrtis Major*, one of the darkest markings on the planet By using it in connexion with the modern observations the rotation period of Mars has been determined to within one fiftieth of a second!

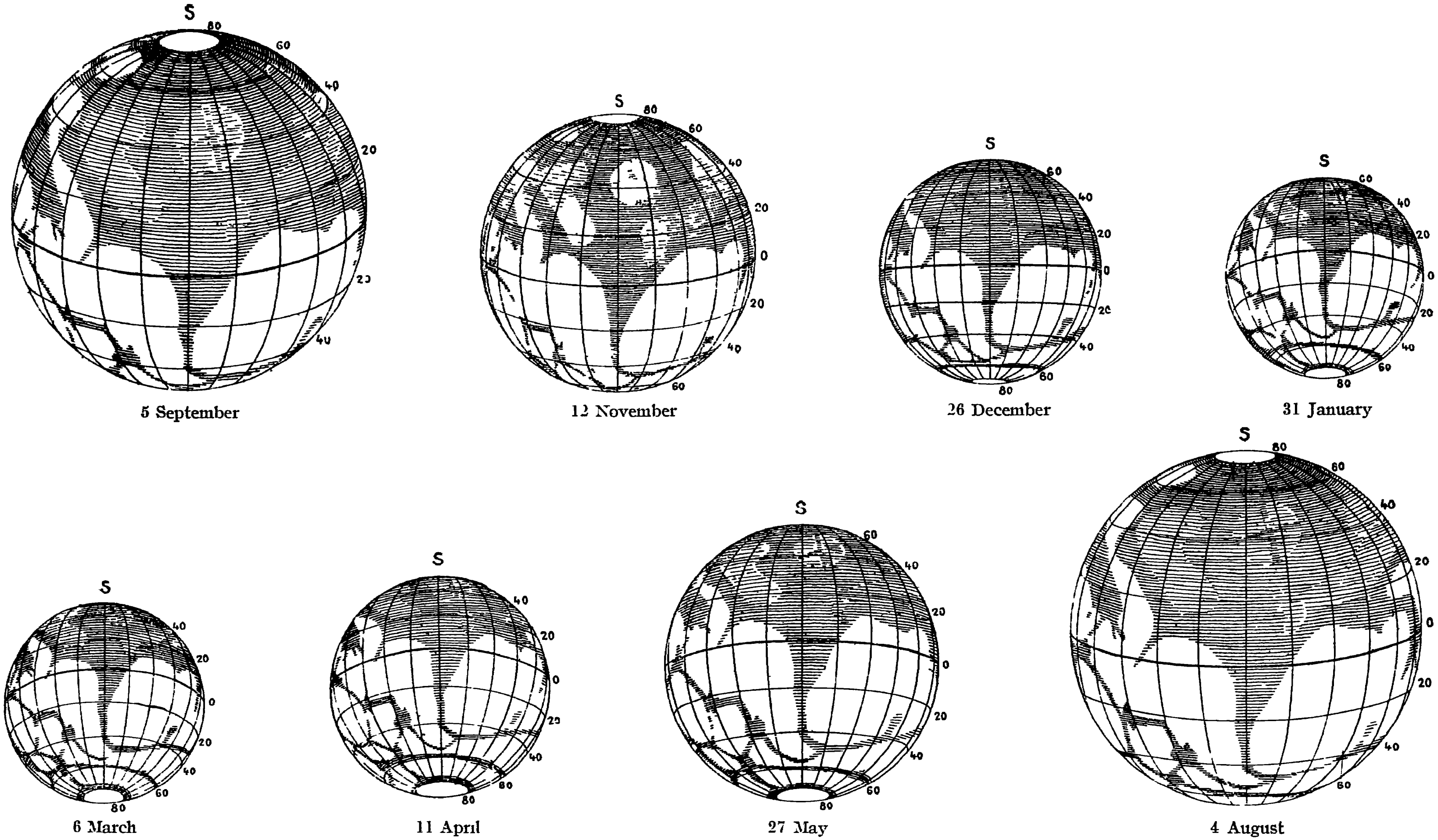
* * * *

The history of Martian discovery dates from the invention of the telescope When Galileo first examined the planet about 1610 he noticed that it did not always appear round Like the Moon it was subject to phase, but unlike the Moon its disc never departed from the complete circle more than does our satellite when three or four days from the Full In 1636 Fontana caught glimpses of dusky markings scattered upon the orange disc of the planet, but many years elapsed before they were seen clearly enough to be drawn The first drawing was made by Huyghens on November 28, 1659 It soon became apparent that the markings had permanent forms, and were being carried

By permission of] [*Mrs Lowell*

THE LOWELL TWENTY-FOUR-INCH TELESCOPE

In 1894 the late Dr Percival Lowell founded an observatory at Flagstaff, in Arizona, primarily for the purpose of studying Mars In addition, however, an immense amount of work has been done in other branches of Astronomy The original telescope was eighteen inches in diameter, but this was replaced in 1896 by the twenty-four-inch telescope made by Alvan Clark This is reputed to be one of the most optically-perfect telescopes ever made The atmospheric conditions at Flagstaff are probably superior to those of any other observatory In 1896 the telescope was moved temporarily to Mexico

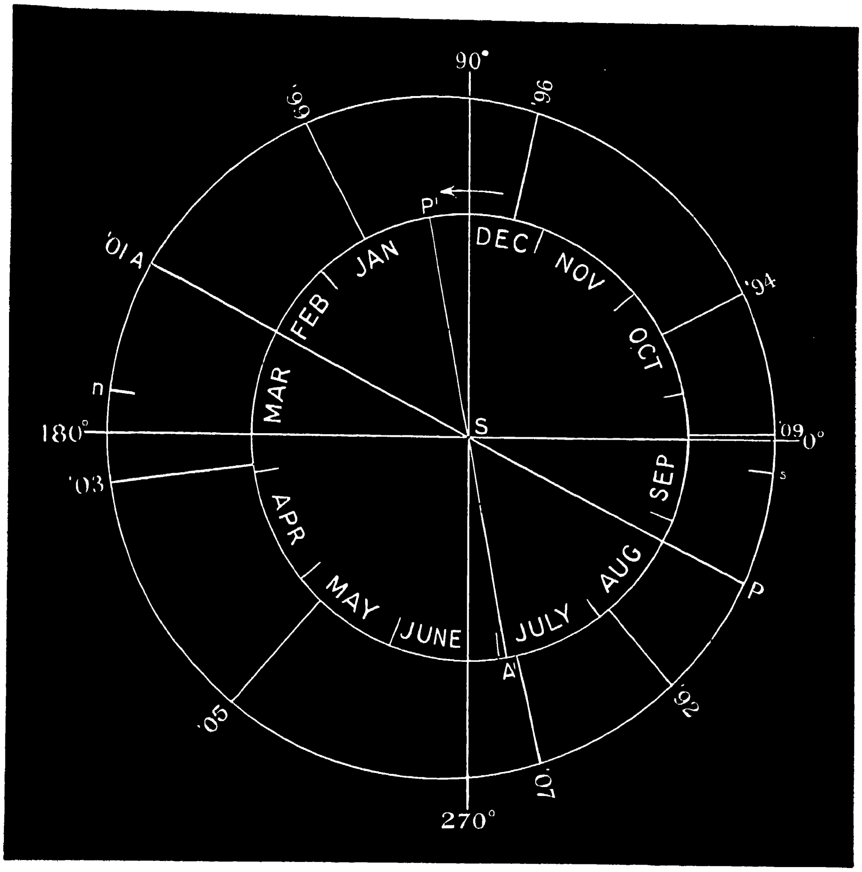


[*From Flammarion's "La Planète Mars"*]

APPARENT SIZE OF MARS AT OPPOSITION

In its revolution round the Sun the Earth overtakes and passes comparatively close to Mars *about* once every two years and two months. These approaches are called "oppositions". Each opposition therefore takes place from one to two and a half months later than that which preceded it two years before. The closest oppositions are those occurring towards the end of August, the most distant towards the end of February. A complete cycle of oppositions—from the closest to the most distant and back again to the closest—occupies fifteen years. The illustration is for the cycle 1877–1894, but is approximately true for any cycle, such as 1909–1924. It shows the relative apparent sizes of Mars seen from the Earth at the eight oppositions which make up one cycle, and illustrates how the South Pole is turned towards us at the closest and the North Pole at the most distant oppositions.

continuously in a west to east direction by the rotation of the planet on its axis In 1666 Cassini made a rough determination of the rotation period, and found that the Martian *day* was about forty minutes longer than our own In 1719 Maraldi noticed at the upper and lower extremities of the disc two white patches which, unlike the dark markings, seemed to be more or less fixed in position He therefore inferred that they were situated at the poles of the planet Furthermore, he found them to be variable in size In the latter years of the Eighteenth Century Sir William Herschel confirmed the general permanence of the dark markings, but showed that they were subject to slight changes in appearance as if they were occasionally obscured by clouds floating in a Martian atmosphere He also proved that the variations in the size of the white pole-caps corresponded with the Martian seasons. From their behaviour he suggested that they were regions of snow analogous to those about our own poles



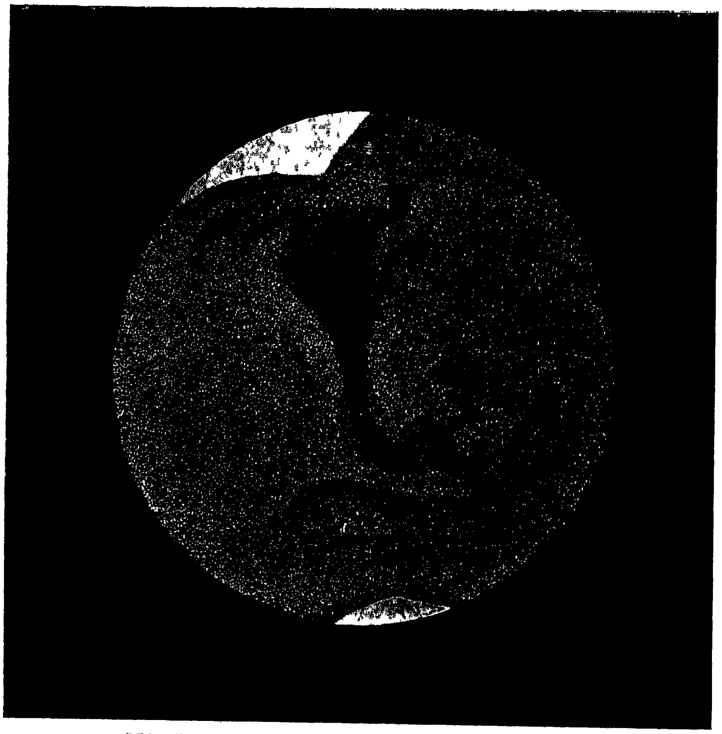
ORBITS OF MARS AND EARTH

The inner orbit is that of the Earth, the outer that of Mars As the two planets revolve round the Sun, S, the Earth catches up Mars and passes it every two years and two months The two planets are then close together and Mars is said to be in "opposition" The dates in the figure show how successive oppositions occur at different months that of 1892 was in August, 1894 in October, &c It will be also clear how the distances vary from one opposition to another, those occurring round August being the nearest, such as in 1892 and 1894, 1907 and 1909 The points P and A are where Mars' orbit is closest and farthest from the Sun respectively P′ and A′ have the same significance with reference to the Earth's orbit

The opposition of 1830 was the closest opposition of the Nineteenth Century. The opportunity was taken by Beer and Madler for making the first systematic chart of the planet This earliest map of Mars was produced in 1840. Its authors assigned to it lines of latitude and longitude similar to those on our own maps Thus did they lay the foundations of Martian "geography" Other maps followed, each better than its predecessor Proctor's in 1869, from Dawes' drawings, Kaiser's in 1872, Green's in 1877, and many others. In these maps the dark markings were called *seas* and the orange regions *continents*, for such was believed to be the nature of the Martian surface

In the year 1877 the world was startled by an amazing discovery Owing to the remarkable proximity of the planet, Giovanni Schiaparelli, the director of the Milan Observatory, had taken the opportunity of making a "trigonometrical survey" of the Martian surface He had not long been engaged upon this work when he became aware of a number of dusky streaks crossing the bright regions, or *continents* These he named *canali*, which is the Italian for "channels" His announce-

ment was immediately met by a quite unwarranted scepticism, due largely, no doubt, to the mistranslation of *canali* by " canals," a word taken to imply something artificial In 1879 Schiaparelli reobserved his original *canali* and discovered many new ones They seemed now much narrower, straighter, and more regular than he had at first supposed In 1881 they seemed even more geometrical in character But what was yet more surprising was that some of them had become double—where before there had been but one line, two parallel lines now lay His critics were dumbfounded nobody had so much as seen these geometrical lines, surely their duplication could only be a proof that Schiaparelli was a victim of illusions ! It was not until 1888 that other observers succeeded in seeing the *canali* Among the first were M Perrotin, with the thirty-inch telescope at Nice, Mr Stanley Williams, with a six and a half inch telescope in England, and the Lick Observers, with the thirty-six inch telescope These also saw some of the *canali* double There could no longer be any doubt that these features had at least *some* objective existence



MARS 1856, APRIL 20—WARREN DE LA RUE
At each of Mars' poles is a white snow-cap These remain in view while the other markings are carried round by the rotation of the planet in twenty four hours thirty seven minutes The dark funnel shaped marking is the *Syrtis Major*

An even more revolutionary discovery was made in 1892 by Professor Pickering in Arequipa He found the *canali* were not limited to the *continents*, several of them could be seen crossing the *Mare Erythraeum*, one of the *seas* In 1894 the late Dr Lowell, director of the Lowell Observatory at Flagstaff in Arizona, and his assistant Mr Douglass, found that the *Mare Erythraeum* was not unique, for *all* the *seas* were crossed by *canali* It at once became clear that the *seas*, whatever they were, were not seas, for it is well nigh impossible to imagine permanent markings of this sort upon the surface of water Moreover, in that same year Dr Lowell pointed out that these dark areas underwent seasonal change, which seemed to indicate that they were, in reality, regions of vegetation

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Mars, like the Earth, is a globe somewhat flattened at its poles Its equatorial diameter is 4,215 miles, thus its surface and volume are respectively one-quarter and one-eighth of the surface and volume of the Earth The weight of Mars, calculated from the motions of its moons, is about one-ninth of the Earth's weight From these figures it can be shown that the force of gravity at its surface is only one-third of its value at the Earth's surface A weight of nine stone on Earth would, if weighed with a spring balance on Mars, only register three stone

The rotation period of Mars upon its axis is twenty-four hours thirty-seven minutes twenty-two and two-third seconds The accuracy of such a determination depends on the length of time over which the observations are extended Using Huyghens' drawing of 1659 we can extend the observations over 260 years hence its supreme importance By using that drawing in connexion with modern observations we have obtained a rotation period accurate to one-fiftieth of a second The axis of Mars

MARS 1862, SEPTEMBER 17—LOCKYER
Although occasionally both snow caps are visible at once, it is more usual for only one to be seen—that which happens to be tilted towards the Earth The round marking on the right is " The Lake of the Sun "

is not perpendicular to its orbit, it is tilted from the perpendicular by an angle of twenty-four degrees Its inclination, therefore, is practically the same as that of the Earth

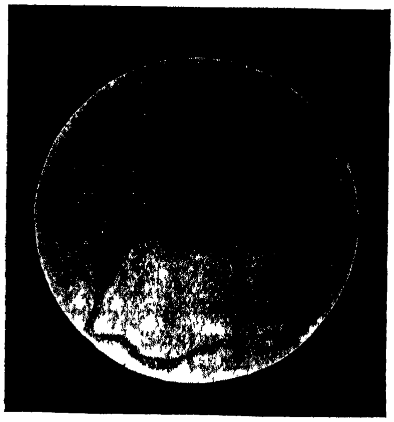
In the telescope Mars appears as a small round disc of an orange colour, upon which dusky, greenish markings can be made out At either one or other of the upper and lower extremities of the disc (sometimes at *both*) a brilliant, round white patch is seen Since the telescope shows everything upside-down the upper patch is called the south pole-cap, the lower patch the north pole-cap The right and left of the disc are designated west and east respectively All drawings and maps are printed upside-down in this way Most of the dark markings are seen to be south of the equator and to extend in a nearly continuous belt all round the planet These are referred to collectively as the " southern seas " The vast stretch of the bright regions north of them is known as the " northern continent," while the smaller bright regions south of them are termed the " southern islands "

[*From Flammarion's " La Planète Mars "*
MARS 1862, OCTOBER 3—LOCKYER
The *Syrtis Major* is visible towards the bottom of the disc It will be seen that the spot separated from its left side (Lacus Moeris) does not appear in the drawing of this marking by Warren de la Rue—indicating some sort of change

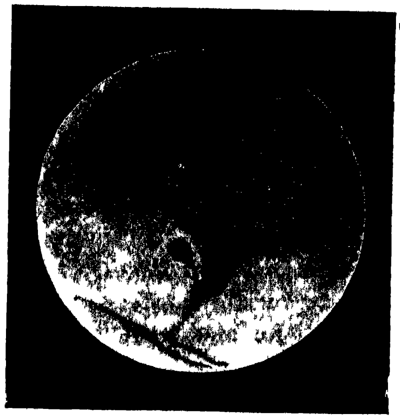
Although direction of the axis of Mars is fixed in space, its tilt to or from the Earth is always changing as the relative position of the two planets alters That is why the appearance of the planet varies so greatly from one opposition to another, for sometimes it is the north pole that is turned towards us, sometimes it is the south pole, whereas more often still it is neither entirely It should be especially noticed that, since Mars is outside the Earth's orbit, the hemisphere that it turns towards us will be the one which is turned towards the Sun and is therefore in its summer season That is the reason why we know more about the summer than about the winter conditions on the planet

* * * *

Herschel's suggestion at the end of the Eighteenth Century that the pole-caps consist of snow, is now almost universally accepted All our experience tells us that the chemical elements which are found in the Sun and stars are, with practically no exceptions, to be found on the Earth Starting with these premises we can, from the appearance and behaviour of the pole-caps alone, eliminate all other

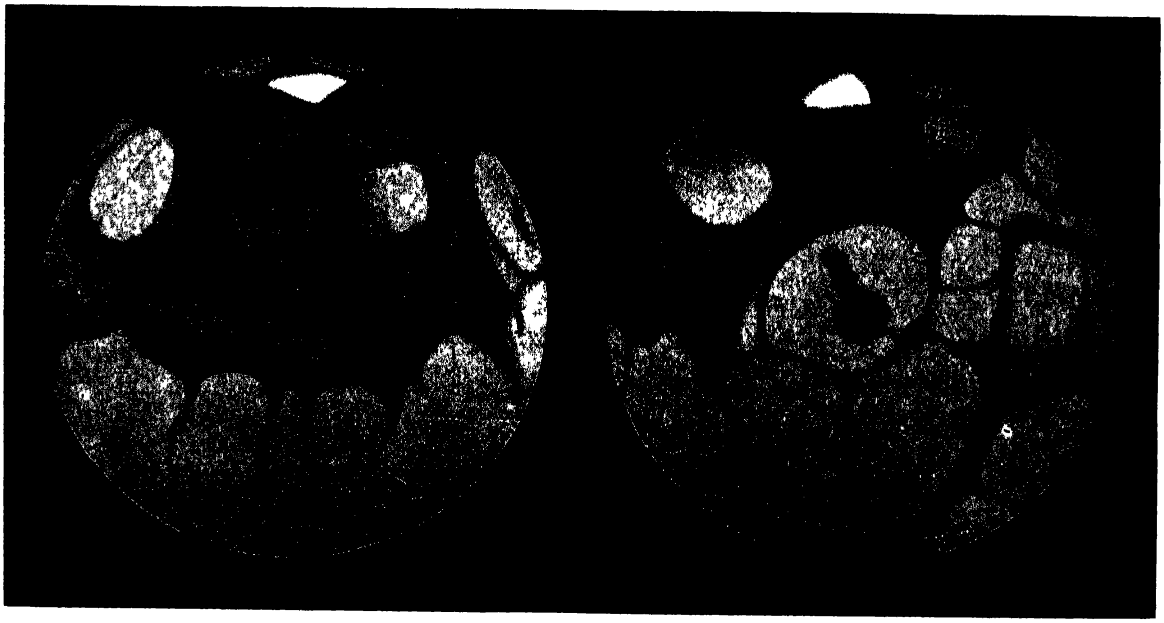


MARS 1864, NOVEMBER 20—DAWES
In this drawing the *Syrtis Major* is disappearing round the left side of the disc The curious forked marking appearing on the right is " Dawes' Forked Bay "



MARS 1864, NOVEMBER 26—DAWES
Here the *Syrtis Major* is near the middle The *Lacus Moeris* is very distinct to its left

suggestions as to their composition, except that of carbon dioxide—that substance we can exclude on physical grounds. Carbon dioxide is a gas which, under suitable temperatures and pressures, may exist either as a colourless liquid like water or as a white solid like snow. Faraday's experiments showed that under a pressure thirty-five times as great as that of our atmosphere it could not exist in the solid form above a temperature of 0° Centigrade, while under a pressure *equal* to our atmosphere the highest temperature at which it could exist was about $-110°$ Centigrade. Now the Martian atmosphere is much rarer than ours, and its pressure at the surface of the planet is certainly not more than a quarter of our own atmospheric pressure. In order that solid carbon dioxide might exist under so small a pressure, the temperature would have to be at least $-150°$ Centigrade and probably much lower. The temperature of Mars, as we shall see, must be a great deal higher than this, which is very nearly as low as the temperature of space itself. Furthermore, Faraday showed that under pressures less than five times that of our atmosphere solid carbon dioxide does *not* become liquid, but passes directly into the gaseous state. But the pole-caps of Mars, as we shall presently see, *melt to a liquid*

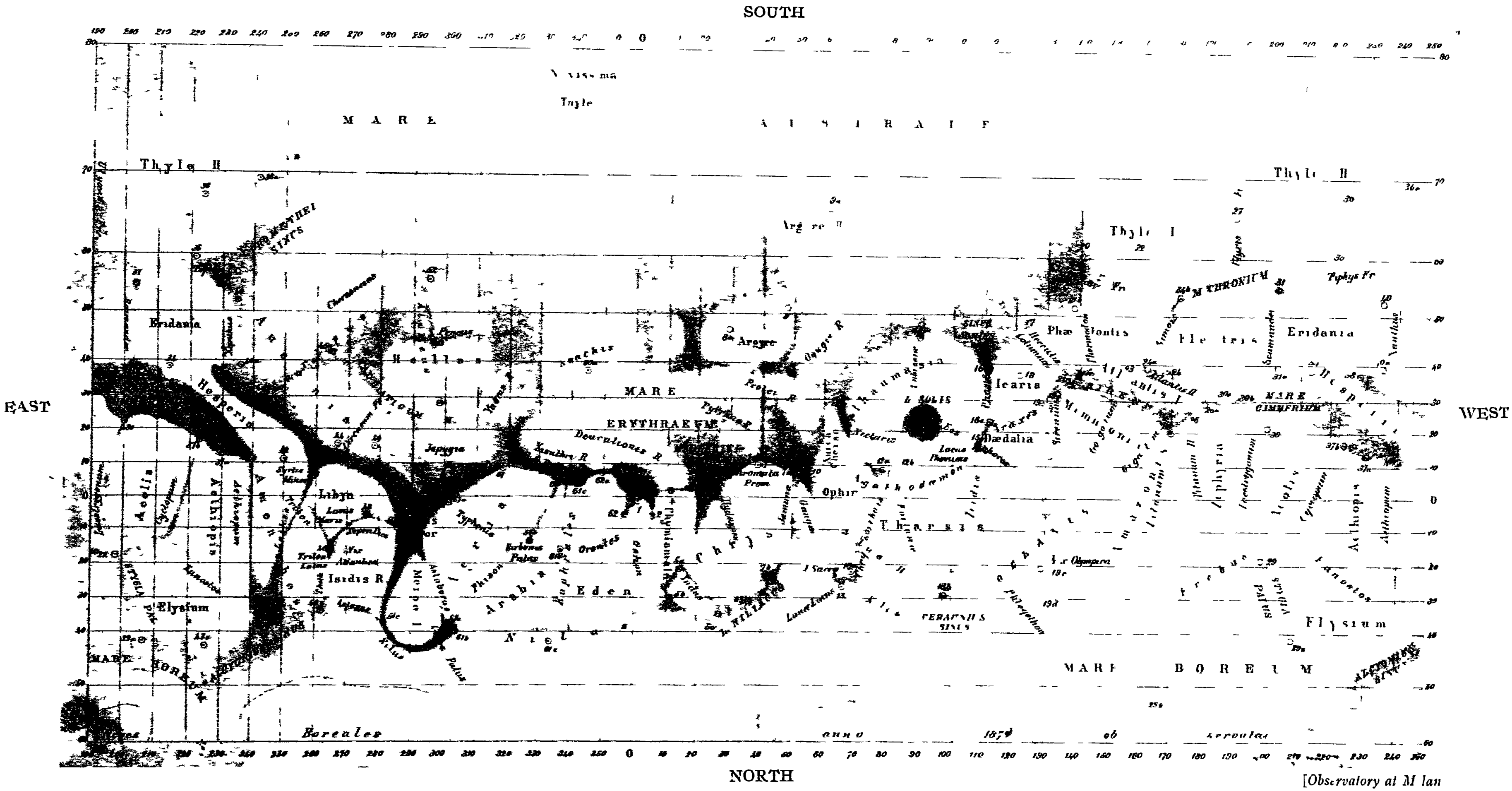


MARS 1877—SCHIAPARELLI

The interest of these, Schiaparelli's earliest drawings, lies in the absence of that regularity of the canals which is so characteristic of his later drawings. Thus, the regularity was not born of preconceived ideas, but, rather, was forced upon Schiaparelli with increasing experience. The canals are the dark streaks crossing the bright areas

Thus, on two separate counts the carbon dioxide theory is untenable. Snow, therefore, the only alternative, must be the composition of the caps.

Early in the Martian spring the polar snows of the hemisphere which is beginning to turn towards the Sun reach their largest development, and the great melting sets in. Even after a few days the cap is appreciably smaller in size. A fine dark line now appears as a girdle circumscribed about its edge, and for about a week grows wider and more distinct. As the melting continues this girdle shrinks in diameter so that it always keeps pace with the border of the retreating snow, while at the same time it decreases very slowly in width. By midsummer the girdle has disappeared and the snow is reduced to a mere speck (in 1894 the southern cap entirely disappeared). The cap now remains unaltered in size for a month or two, when the winter fall sets in and the snows once more begin to increase. Lowell found the colour of the dark girdle to be a deep blue-green, and concluded that it was probably water. Others maintained that it was merely an illusion, due to an effect of contrast. Professor Pickering, however, examined it with a *polariscope*, an instrument which distinguishes



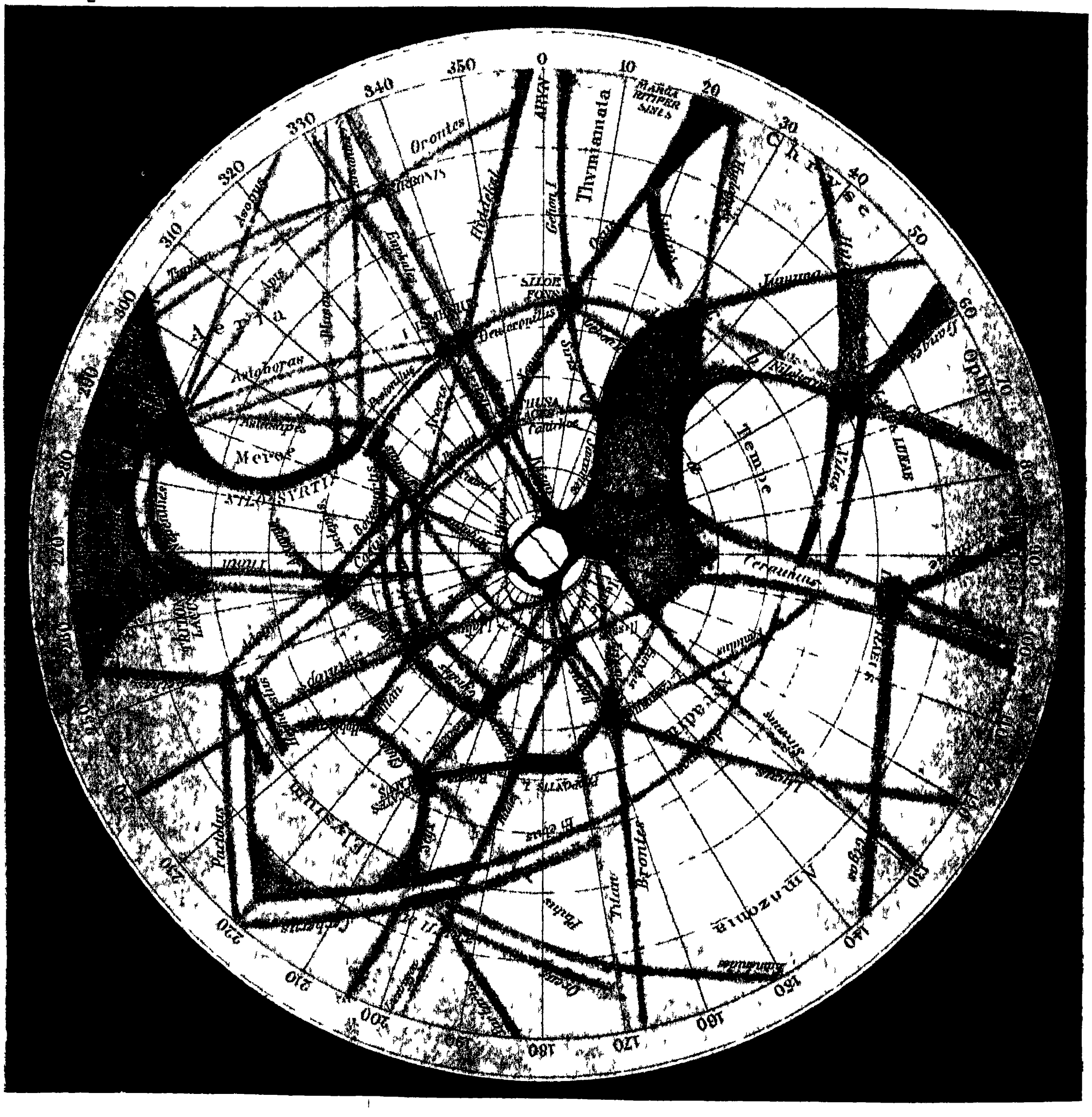
[Observatory at Milan

MAP OF MARS 1879—SCHIAPARELLI

Since astronomical telescopes show everything upside-down, all maps and drawings of Mars are printed with the *North at the bottom* Lines of latitude and longitude have been assigned similar to those on our own maps It was originally thought that the dark markings were seas and the bright markings land, but now we believe them to be vegetation and desert respectively Nevertheless the old names are retained, the dark regions being called *M* or *Mare* ("Sea"), *Sinus* ("Bay"), and *L* or *Lacus* (Lake) In this early map of Schiaparelli the canals are not drawn so regular as in his later ones

between the smooth surface of a liquid and the surface of a solid, and found that it was liquid. Since the only possible liquid is water, we must conclude that the girdle is a temporary *polar sea* formed around the melting snow-caps.

When the snows have dwindled considerably, dark rifts appear in them, extending inwards from the polar sea and later breaking them up into several isolated parts. These rifts always appear in the same places. M. Jarry Desloges thinks that they are irregularities in the level of the ground. But Lowell found that they are identical with certain polar *canali*, which are visible when the snows have disappeared, and believed them to be strips of vegetation that tend to hasten the melting of the snow beneath which they are buried.



NORTH POLE OF MARS IN SUMMER

In this chart, made by Schiaparelli in 1888, the snow-cap (the white patch at the centre) has grown very small from its summer melting. In winter it has nearly five times the diameter—covering the circle on which *Tempe* and *Arcadia* are printed. The way in which the canals radiate outwards from the cap is seen most strikingly. Lowell pointed out that such an arrangement was to be expected from his theory of the canals, for according to that theory the canals were made (artificially) for the purpose of conveying the water from the melting snows to the more distant parts of the planet.

MARS 1879 SCHIAPARELLI
In this year Schiaparelli drew the canals with more regular forms than in 1877 The dark round spot with two canals is the Lake of the Sun (*Solis Lacus*)

The snow-caps on Mars come down in the winter somewhat nearer to the equator than those on the Earth, while in the summer they shrink to a much greater extent These differences, which at first sight might appear to contradict one another, are due to three causes First, the Martian seasons are nearly twice as long as our own, so that there is more time both for the precipitation of the snow and for its subsequent thawing Secondly, owing to the entire absence of large seas, the Martian atmosphere must be much drier than our own, the snowfall therefore will not be so deep and its dissipation will be more rapid Thirdly, the greater elongation of the planet's orbit must mean an exaggeration of the seasons a greater difference between the summer heat and the winter cold

The two snow-caps of Mars also differ slightly from one another The southern cap is the larger in the winter and the smaller in the summer Now that is exactly what we should expect, for whereas the southern hemisphere has a longer and colder winter, it has a shorter and very much hotter summer than the northern hemisphere

We thus see that the theory of snow, which we were earlier forced to adopt, seems to explain completely the phenomena that we observe

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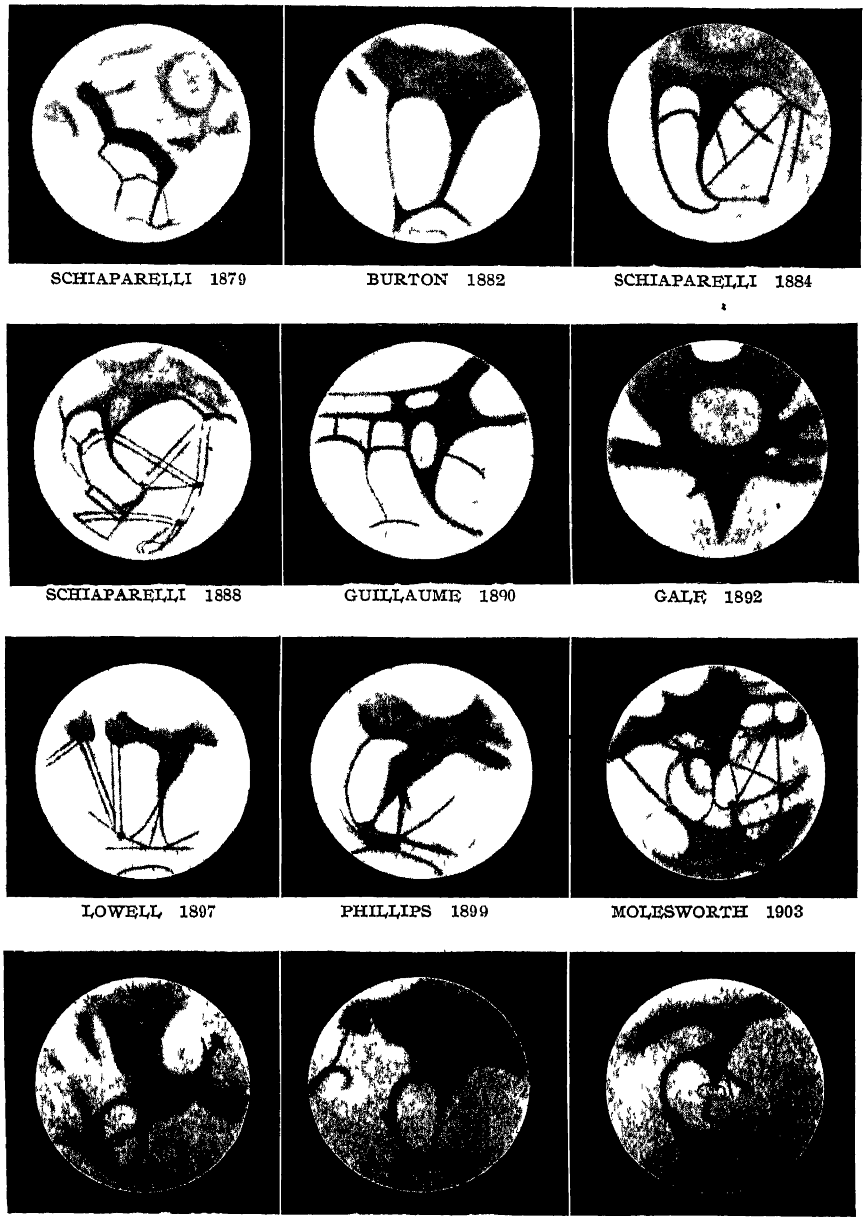
The discovery of Professor Pickering, that the dark areas are crossed by the *canali*, dealt the death-blow to the theory of their oceanic character They are now generally believed to be areas of vegetation Yet the names with which they were baptized by Schiaparelli in the Latin tongue are still retained, *seas* and *lakes* they are called, and not altogether inappropriately, for long ago before Mars lost most of its water they may well have formed the beds of the Martian seas

Although, broadly speaking, permanent, these markings are subject to considerable change But our interpretation of such change, whether seasonal or irregular, is largely hampered by our inability to observe the planet for more than about six months at each opposition, *i e*, over a period equal to only a quarter of a Martian year In order to cover a complete cycle of Martian seasons, it is, therefore, necessary to continue observations over many oppositions, and even then we are not justified in assuming a change to be *seasonal* until we have seen it repeated at several presentations of the same season It is possible that many changes which we still believe to be irregular may yet reveal a seasonal character

MARS 1879—SCHIAPARELLI
The dark funnel shaped marking is the *Syrtis Major* The narrow canal, with a round spot, curving from its left side downwards, and then running vertically, is *Nepenthes-Thoth*—which sometimes is very wide

Probably the most important work in this connexion is that of Lowell and his assistants at Flagstaff, where the planet has been under regular



By permission of] [*Mr H Thomson*

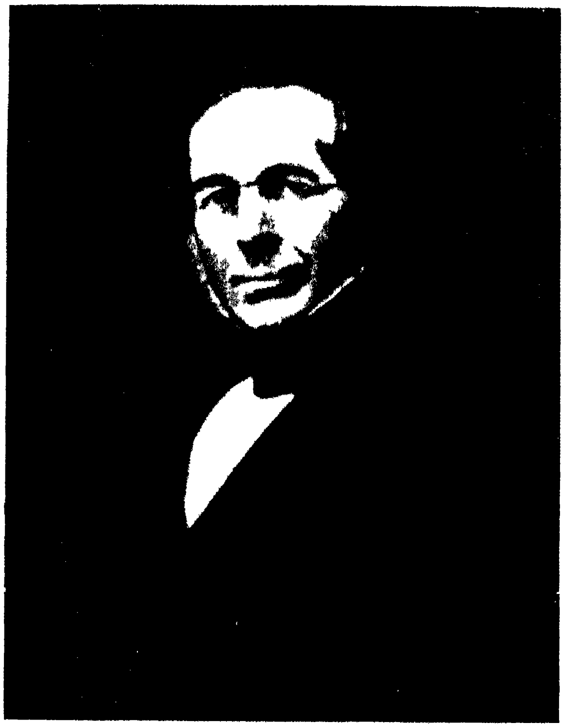
CHANGES IN THE SYRTIS MAJOR

This interesting series of drawings was collected by Mr H Thomson It gives views of the *Syrtis Major* by many of the greatest observers between 1879 and 1918 Although undoubtedly some of the changes here shown are due to idiosyncracies of the different observers, many of them are certainly real The most marked variation is that in the canals *Amenthes* and *Nepenthes-Thoth* *Amenthes*, a vertical line parallel to *Syrtis Major* and on its left, was visible in 1882, 1897 (double) and 1899 *Nepenthes-Thoth*, which curves downwards from the left side of *Syrtis*, was visible in 1879, 1888, 1903 and (very dark) in 1911, 1916, 1918 In 1884, 1890 and 1903 both canals were seen together

observation since 1892 Their evidence alone is absolutely definite in showing that many of the changes are seasonal Scarcely less convincing is the evidence which M Flammarion obtained from a discussion of all the observations prior to 1901

The cycle of changes may be briefly summarised Just after midsummer, when the snow of the summer pole is almost entirely melted, the dusky markings in the immediate vicinity of the cap begin to darken This darkening proceeds in the manner of a wave slowly from the melted pole towards the equator, and then, crossing the equator, advances into the low equatorial latitudes of the opposite hemisphere (the winter hemisphere) Thus is the season of the darkening later and later as we depart farther from the summer pole In the late autumn the markings begin to fade, reaching their faintest soon after midwinter

Simple as this cycle may appear, it is in reality rather more complicated The change is not merely one of light and shade, it is also a change of colour Again, the regions near the equator are affected by the melting of the snow not only of their own hemisphere but also of the opposite hemisphere, so that these portions of the planet's surface go through the cycle *twice* in a year In 1903, when it was midwinter in the southern hemisphere, Lowell found the *Mare Erythraeum*, a sea just south of the



From] [" *Knowledge*"

WILLIAM RUTTER DAWES

Dawes—sometimes called the "eagle eyed Dawes"—was among the greatest of the observers of the last century It was from his drawings that Proctor compiled the famous map of Mars in 1869

By permission of] [*Brit Astron Assoc*

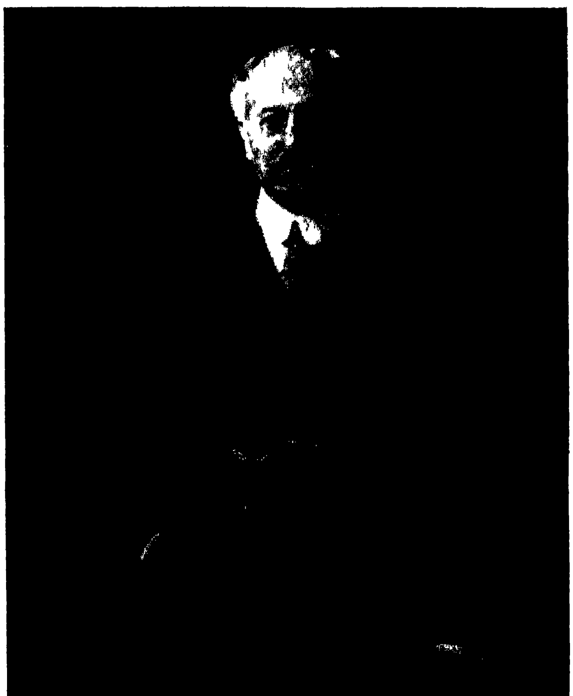
NATHANIEL E GREEN

Green's drawings of Mars during the period 1859–1898 must ever remain famous His observatory was at St John's Wood In 1877 he went to Madeira to observe the close approach of Mars during that year

From] [*Pub of Astron Soc of Pacific*

GIOVANNI VIRGINIO SCHIAPARELLI

Schiaparelli, director of the Milan Observatory, discovered the canals of Mars and the phenomenon of their doubling Up to his death in 1910 he believed them to be *natural* features



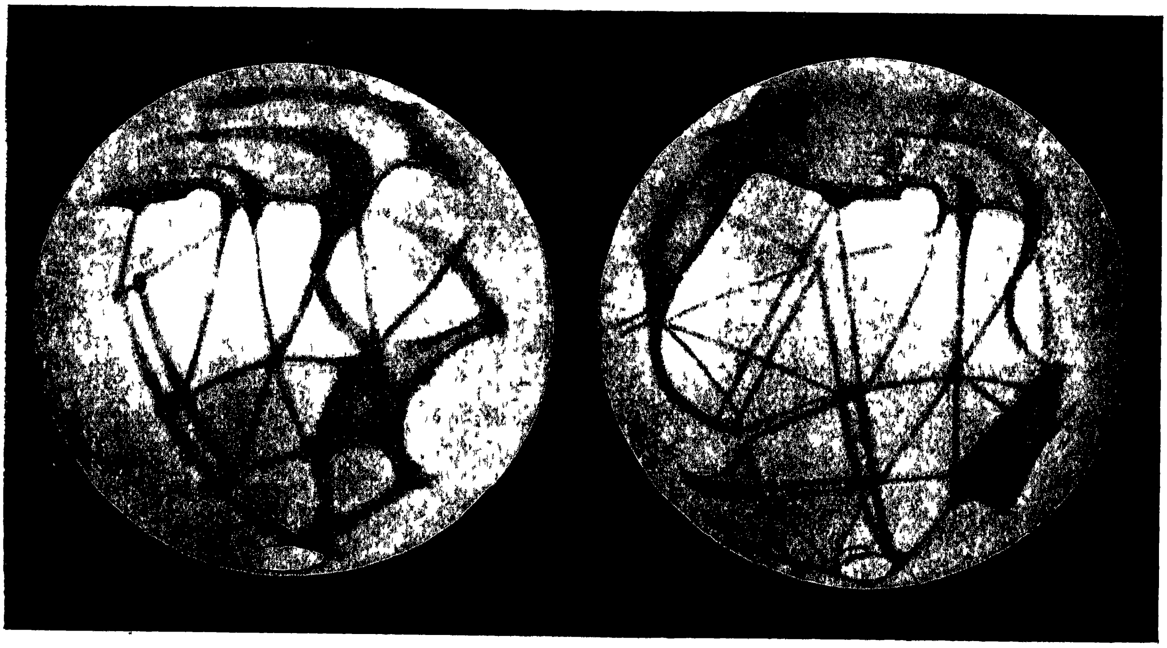
By kind permission of] [*Mrs Lowell*

PERCIVAL LOWELL

No man ever had more experience in the observation of Mars than had Lowell His work represents one of the greatest steps in Martian discovery From 1894 to 1916 he directed the famous observatory which he had founded

equator, to be of a faint green colour By the middle of the Martian January it had changed to a dark brown, which then gradually faded out A light green now appeared which, starting from its northern *shores*, proceeded southwards until it had converted the entire *sea*, by the end of February, to a brilliant green The theory of vegetation explains this in a most striking manner The change from green to brown and the fading of the latter soon after midwinter would represent the coming of the autumn tints and the falling of the leaves, which had been nourished by the moisture emanating from the *southern* polar snows , while the reappearance of the green in the Martian February, travelling from north to south, would represent the budding vegetation of a *second* spring brought in by the moisture proceeding from the *northern* snows

But in addition to changes that are seasonal there are others, many and considerable, which are apparently irregular Probably the best known example is the case of the *Syrtis Major*, one of the most conspicuous of the Martian *seas* The drawings of Green and others in the middle of the last century give this *sea* a very different shape from that given it by the drawings of the last thirty



MARS 1888—SCHIAPARELLI

These later drawings give the canals perfectly regular forms Some are double , several of them intersect in single points , and wherever they connect with the dark markings there is a well marked projection The double canal, *Euphrates* (in both drawings), running down to the north pole-cap, is nearly 3,000 miles long

years Again, the *Nepenthes-Thoth*, usually drawn as one of the faint *canali* issuing from the eastern shores of the *Syrtis Major*, has become, since 1909, one of the darkest markings on the planet Lowell found that many of these irregular changes were associated with changes of a similar kind in the *canali* One system of *canali*, after existing for several years, would suddenly be replaced by a totally different system, while at the same time the *seas* in the vicinity would take on a slightly different configuration The reappearance a few years later of the original system would be accompanied by a reversion of the *seas* to their previous form Such changes, he therefore concluded, were due to an alteration in the manner in which the water was fed to these regions by the *canali* On the other hand, M Jarry Desloges considers this sort of change to be due to meteorological phenomena to obscurations by cloud and mist, to havoc wrought by violent hurricanes Moreover, he would invoke these agencies to explain many of the changes which others believe to be seasonal To the writer it seems probable that both processes are, in part, responsible for these diversities in the appearance of the

vegetation Until recently the tendency has probably been to underestimate the importance of the Martian atmosphere in relation to change

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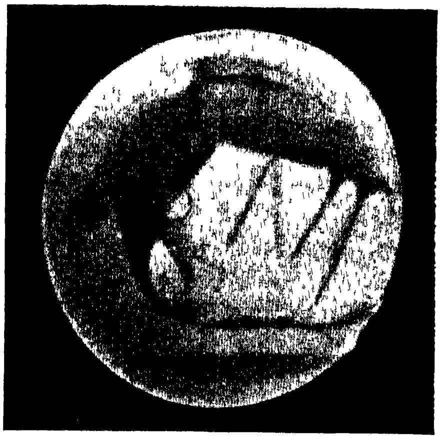
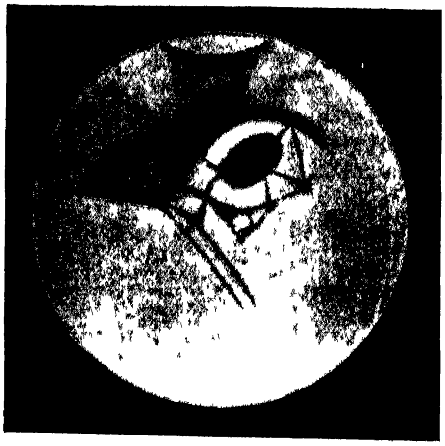
The orange regions cover three-fifths of the Martian surface Except for slight modifications in the intensity of their orange colour, they show no signs of change Sometimes the colour is accentuated, sometimes it gives place to a pale-lemon or white It is believed that this is due to variations in the clearness of the Martian atmosphere, to clouds, mists, sandstorms, or even frosts Those parts of the orange regions which border upon the seas, more especially the narrow isthmuses Atlantis and Hesperia, which connect the southern *islands* with the northern *continent*, are liable to temporary invasions of vegetation during the height of the summer But except for these small and temporary lapses the bright regions seem to be destitute of all fertility They are believed, indeed, to be deserts deserts of red sand It has been suggested that this redness is not real, but is due to an atmosphere, even as is the redness of our sunsets But the rarity of the Martian atmosphere renders such an hypothesis untenable Red, they must really be



MARS 1890, JULY 6—KEELER

It was not until eleven years after Schiaparelli's discovery of the canals that anyone else succeeded in seeing them This is one of the early drawings of the canals made with the thirty-six inch telescope at the Lick Observatory



MARS 1892, AUGUST 17—HUSSEY

Drawing made with the great Lick telescope showing canals round *Solis Lacus*, sometimes called the "Eye of Mars"—the large round black spot, and the "Bay of the Dawn" (*Aurorae Sinus*) from which the double canal issues

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In 1879 Schiaparelli detected a small, dazzling white spot about twenty degrees north of the equator This he took to be snow and christened it *Nix Olympica* Since then a large number of these spots have been observed They are, on the average, about 100 miles in diameter, they are completely isolated from one another, they are very sharply defined, and their whiteness is hardly inferior to that of the polar snows It is almost certain that they are not cloud or mist, for their positions are absolutely fixed, and although their existence is not permanent they may remain unchanged for months, furthermore, when they recur, they do so in exactly the same places It is also extremely unlikely that they are snow, as Schiaparelli believed them to be, for not only do they make their appearance in the summer, the hottest time of the year, but they also tend to be situated in the tropical regions, the hottest parts of the planet They present, in fact, a phenomenon entirely unexplained It has been suggested very tentatively that they may be crops

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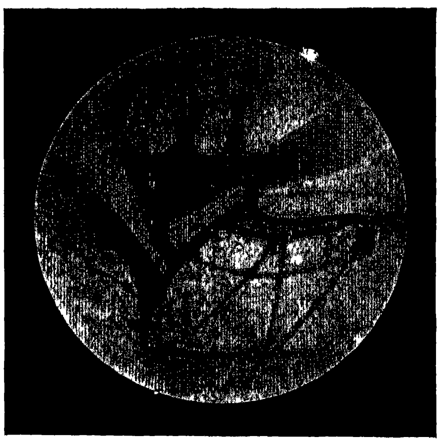
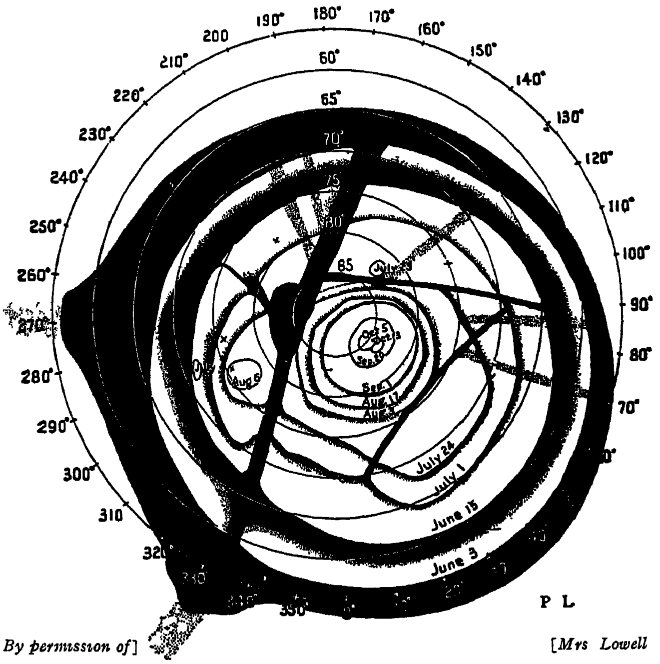
White masses obscuring parts of the planet's surface have



MARS 1894, OCTOBER 7—STANLEY WILLIAMS

Mr Stanley Williams was the first man in England to see the canals, with only a six and a half inch telescope The lowest horizontal canal is *Protonilus*, that above and parallel to it is *Typhon* and *Orontes*, the vertical ones from left to right are *Phison*, *Euphrates*, and *Hiddekel*



By permission of] [Mrs Lowell

MELTING OF SOUTH POLAR SNOWS OF MARS, 1894
In early spring the snow cap begins to melt and dwindle in size A dark belt of water (the polar sea) appears around its edge, and keeps pace with it as it shrinks The size of the cap on various dates is indicated The centre of the cap does not quite correspond with Mars' geographical pole

been observed from the earliest times Their rapid changes in position and shape, their complete or partial opacity and their ultimate dissipation, show that they are some form of cloud or mist Lowell distinguished two types white and yellow, and made the suggestion, now generally accepted, that they are analogous, the first to ordinary cloud, the second to sandstorms He believed them to be fairly rare Later observations, especially those of M Jarry Desloges and the British Astronomical Association have shown that they are much commoner than Lowell supposed M Jarry Desloges finds that the small, thin clouds are of daily occurrence, and he attributes many phenomena to obscuration by them The large clouds are less common In 1909 a tremendous yellow cloud veiled most of the southern *seas* for a whole month In 1911 a yellow cloud with an area of eight million square miles stretched from the south pole, blotting out the *islands*, *Hellas* and *Argyre*, and most of the *Mare Tyrhennum* In June 1922 Dr Slipher at Flagstaff photographed a large white cloud which for four days hung over the *coast* of the *Margaritifer Sinus* Great masses of cloud or mist are invariably seen over the melting snows some time before midsummer Measurements of the height of clouds are extremely difficult Probably they float at the same sort of levels as our own clouds Lowell's measurements however indicated a height of more than fifteen miles above the surface for some of the larger masses

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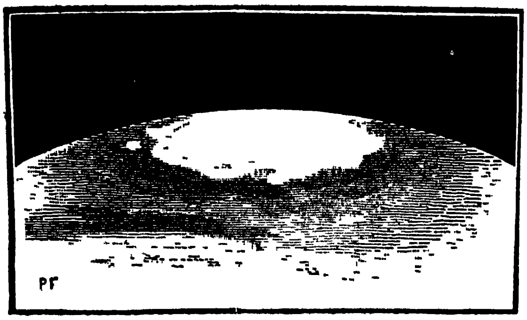
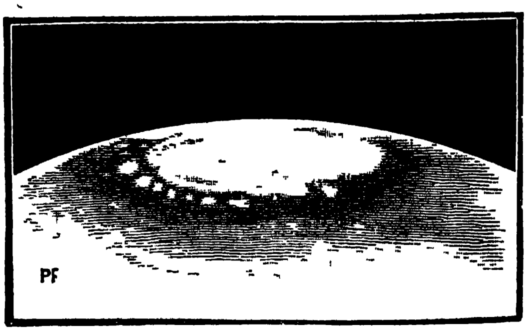
There frequently appear upon the western edge of the planet's disc—that part which is just coming into our view and on which the Sun is rising—large white patches which rapidly dwindle, and disappear before reaching the centre of the disc, where it is midday These are usually called *hoar frosts*, but whether they are hoar frosts or low lying *morning mists* it is impossible to say

* * * * *

We have now ample evidence of an atmosphere, the clouds, sandstorms, the hoar frosts or morning

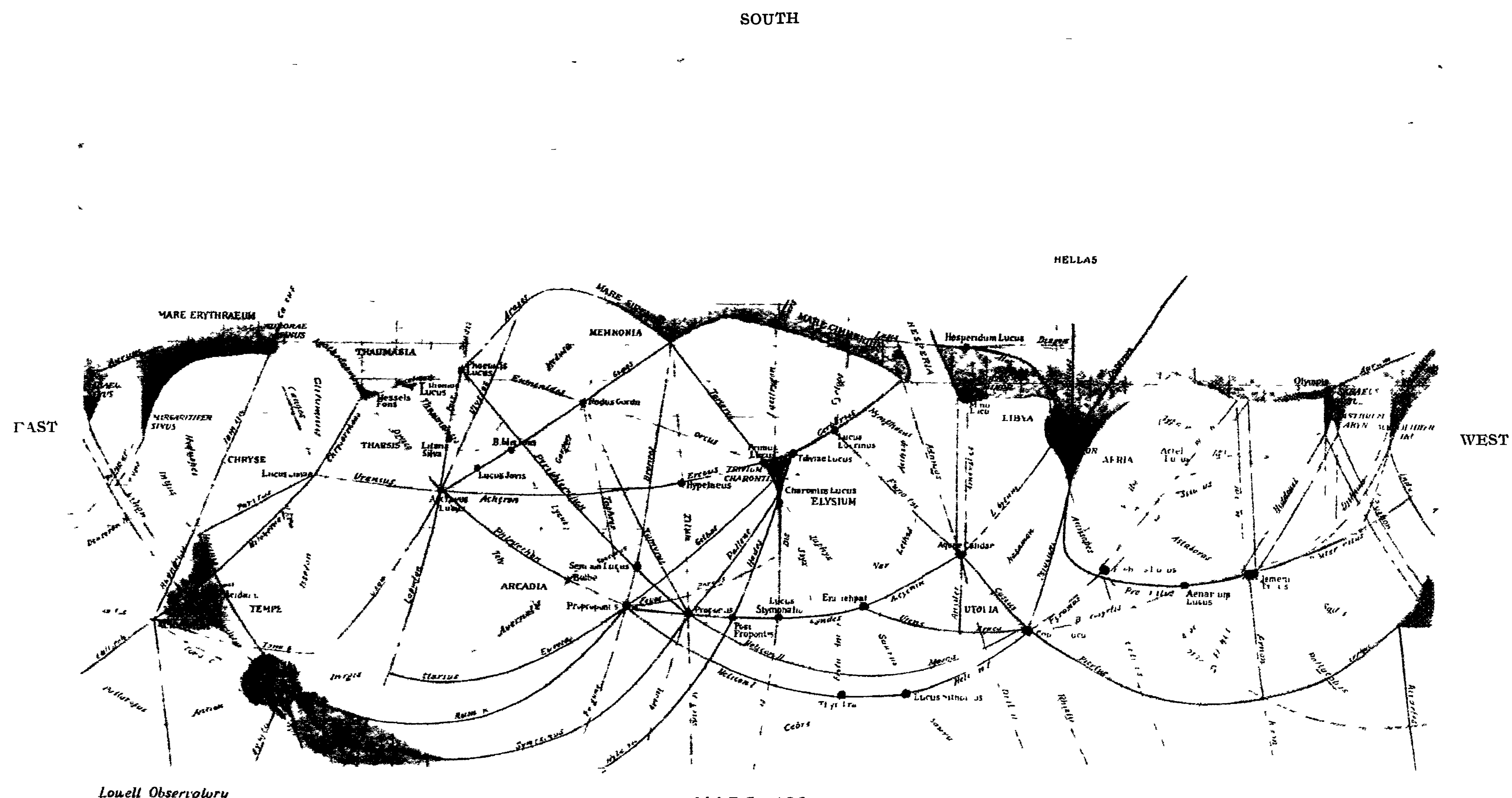


September 1, 1877



September 8, 1877

SOUTH POLAR SNOWS OF MARS—GREEN
When the pole is turned towards the Sun, in the Martian summer of that hemisphere, the snow begins to melt and becomes surrounded by a dark belt—the polar sea Sometimes small portions of the snow-cap become detached



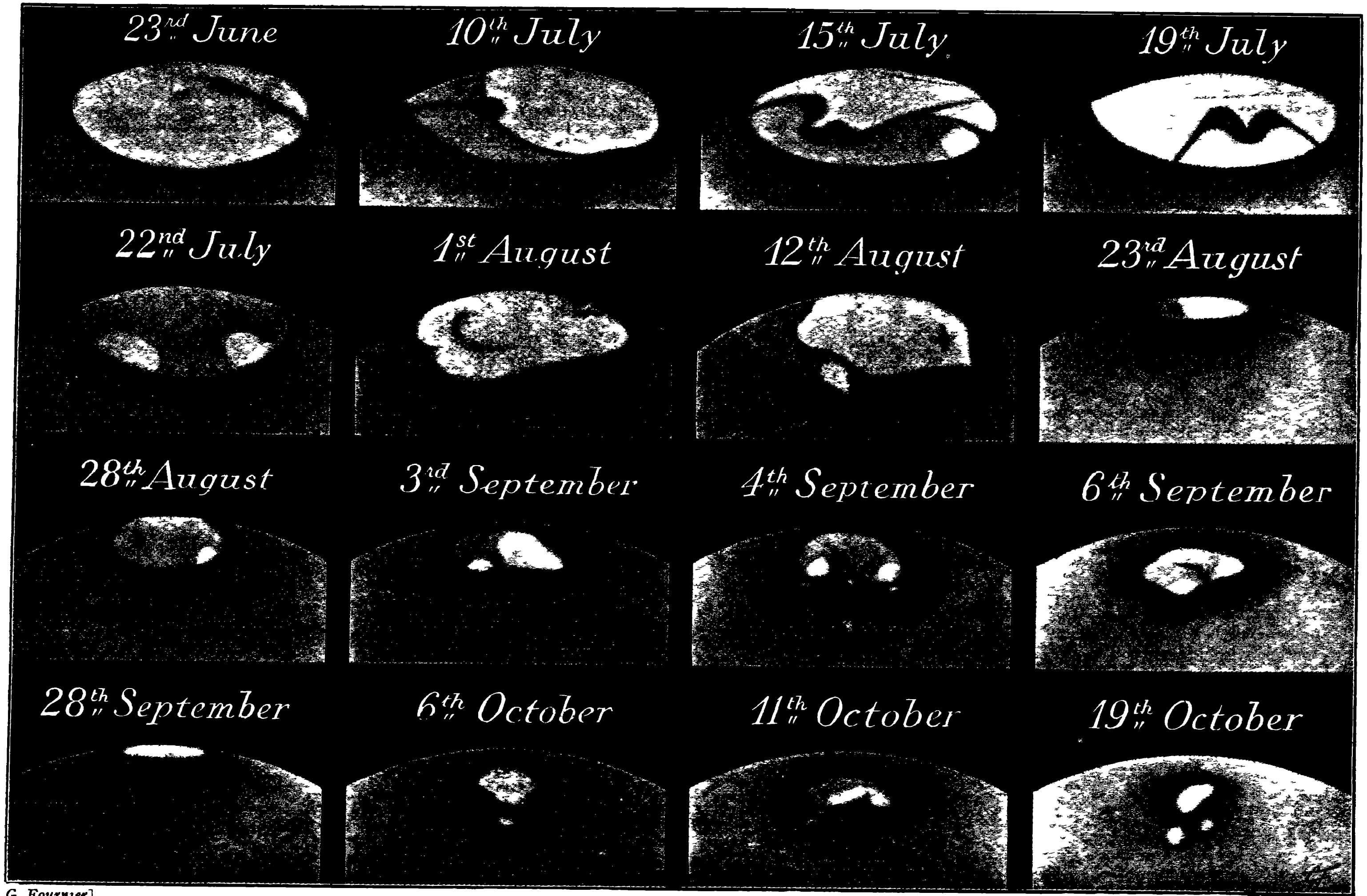
MARS—1901

By permission of [Mrs Lowell

NORTH

CHART OF MARS 1901—LOWELL

Lowell saw and drew the canals as perfectly geometrical lines Many astronomers see the canals with more irregular forms If, however, Lowell's drawings are accepted it seems well-nigh impossible to explain the canals as natural features Their straightness and network arrangement *look* most unnatural Lowell believed them to be artificial He did not claim that we see the canal itself, but merely the vegetation growing on its banks The canals vary in darkness with the seasons, as we should expect if they were strips of vegetation Some of the canals occasionally become double, it is believed by some that the doubling always occurs at certain seasons

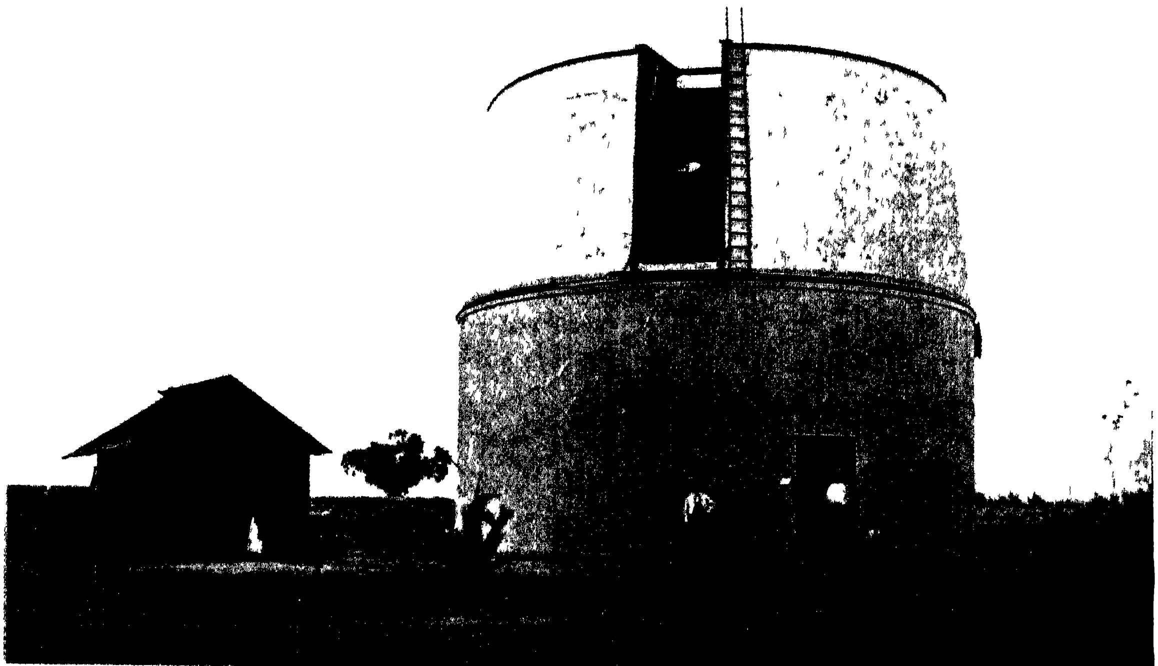


G Fournier] [*By kind permission of M Jarry Desloges*

THE SNOW OF MARS' SOUTH POLE, 1909

This interesting series of drawings was made by M G Fournier partly at Le Massegros and partly at Le Revard (Savoie), two of M Jarry Desloges' observatories It illustrates the gradual dwindling in the size of the snow during its summer melting, and the manner in which small portions of it become detached Dark rifts can be seen running across the cap These always seem to appear in the same positions It is suggested that they are produced by irregularities in the level of the ground Some have maintained that in these places the snow is melted prematurely by vegetation buried beneath it

mists, and the existence of vegetation testify undeniably to it But there is more the markings on the planet appear to be partly obscured, apart from local clouds or mists, as they approach the edge of the disc This could not happen if there was no atmosphere, while the presence of one would necessarily cause an opacity at the edge of the disc, where we should be looking through a greater thickness of air Furthermore, Dr Slipher in 1914 photographed the spectrum of Mars at Flagstaff and found it to contain water-vapour This is a definite proof of an atmosphere Those photographs also showed that there was more water-vapour over the melting snows than over the equator, hence they also afforded the first experimental proof that the poles are *solid water* or snow With the exception of water-vapour we have no direct evidence of other constituents in the Martian atmosphere But for certain physical reasons the existence of water-vapour is a very strong indication of the presence also of oxygen, nitrogen, and carbon dioxide gas Moreover, if we admit, as we surely must do, the reality of the vegetation, the conclusion that



By permission of] [*Mrs Lowell*

THE LOWELL TELESCOPE IN MEXICO, 1896

In order to find, if possible, a site where the atmospheric conditions were even better than those at Flagstaff, Arizona, the twenty-four inch telescope and forty-foot dome were removed in 1896 from Flagstaff and set up at Tacubaya, Mexico This gigantic move only interrupted the observations of Mars between November 7 and December 30

these last three gases are present must immediately follow, for without them vegetation, as we know it, is impossible The Martian atmosphere would thus appear to contain the same constituents as our own

Lowell, on theoretical grounds and from his observations of cloud, concluded that the pressure of the atmosphere at the surface of Mars was about one-seventh of our own atmospheric pressure More recent observations tend to show that Lowell underestimated the extent of the atmosphere and its pressure at the surface, and indicate that the pressure probably lies *between one-quarter and one-sixth* of our own

Now the highest permanent dwelling-place is situated in the Andes under a pressure of *half* an atmosphere Temporary ascents have been made in balloons to altitudes where the pressure is about *one-third* of an atmosphere If we, who are unaccustomed to it, can exist under such low pressures,

it would not seem impossible that other quite different forms of animal and vegetable life might be evolved, through the course of ages, to withstand the not greatly inferior pressure at the surface of Mars.

* * * * * * * *

Since Mars is at a greater distance from the Sun, the heat which it receives is only about forty-five per cent. of the amount of heat received by the Earth. Its atmosphere, however, is abnormally clear, so that the heat which actually penetrates the air, and, escaping absorption, reaches its surface, is but slightly less than that which reaches the Earth's surface after passing through its much denser atmosphere. The day temperatures of Mars in the Sun should not, therefore, be greatly different from our own, while the larger number of cloudless days would tend yet further to diminish this difference and to raise the temperature. On the other hand, the rarity of the atmosphere would favour the more rapid escape of heat and cause a much bigger fall of temperature at night. There is now however reason to believe that this escape of heat is largely prevented by a very considerable formation of cloud during the Martian night. If that is so, the night temperatures also should not be very much lower than those on Earth.

* * * * * * * *

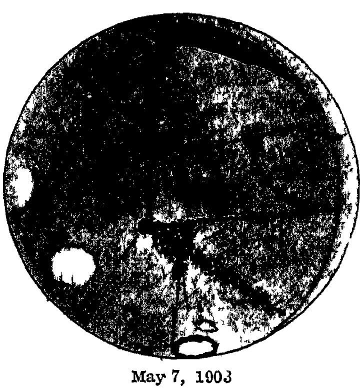
We come now to the much-disputed question of the *canali*. Let us first summarise those facts about them which are *not* disputed. The *canali* cross the *seas* and *continents* indifferently, running for hundreds of miles and, in some cases, for three or four thousand miles in practically straight lines

February 25, 1903

March 30, 1903

April 3, 1903

May 4, 1903



May 7, 1903

July 18, 1903

By permission of] [*Mrs Lowell*

DEVELOPMENT OF THE BRONTES—LOWELL

The drawing of February 25, before the Martian midsummer, shows the canal, *Brontes*, running vertically downwards (to the left of the middle) towards *Propontis* (the left one of two dark spots). On March 30, some days after Martian midsummer, the *Brontes* disappeared. Its gradual reappearance, developing slowly from *Propontis* upwards across the disc, is seen in the remaining drawings. Lowell believed that this darkening of a canal represents the growth of vegetation on its banks brought about by water travelling, in this case, southwards (upwards) from the north polar snows, which are here seen (much reduced by melting) at the bottom of the discs

September 14
September 15
September 16

September 15
September 15
September 18

By kind permission of] [*M Jarry Desloges*

MARS 1909—G FOURNIER

These beautiful drawings were made with the 11 3 inch telescope at Le Massegros, Lozère, where M Jarry Desloges has one of his many observatories Like Lowell, this astronomer has recognised the supreme importance of a site *with perfect atmospheric conditions* for observing the planets The double canal, *Phison* (in top and bottom drawings on the left), is seen single in the two middle drawings M Jarry Desloges explains such a change as possibly due to obscuration by cloud Other changes also are seen There is a cloud or mist lying just north of the south polar snow cap in the lower four drawings

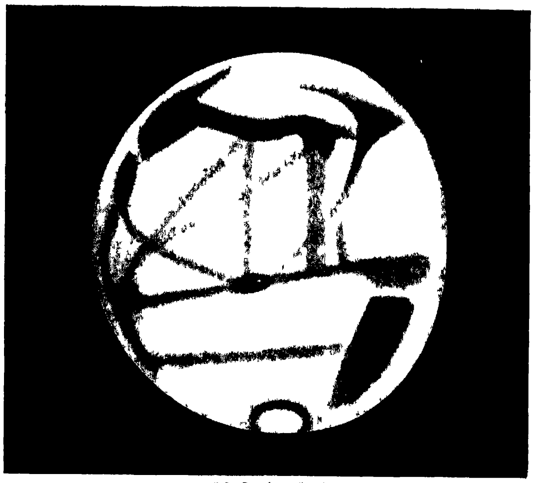
November 11
November 13
November 21

November 12
November 13
November 24

By kind permission of] [*M Jarry Desloges*

MARS 1909—V FOURNIER

These drawings were made with the 11 3 inch telescope at Le Massegros, Lozère The upper four illustrate the extremely complicated system of canals in the neighbourhood of the Lake of the Sun (*Solis Lacus*) and the beak-shaped Sea of Sirens (*Mare Sirenum*) In the lower two *Hellas* appears abnormally w' ite disappearing round the left edge, this is possibly due to a deposition of hoar frost Below it is the *Syrtis Major*, while near the centre of the disc is the "Forked Bay" through which the zero line of longitude runs—the line on Mars corresponding to the Greenwich Meridian on Earth To the right of this is the pointed *Margaritifer Sinus* or "Pearl-bearing Gulf"



1918, *April* 22

W H Steavenson] [*By permission of the Astronomer Royal*

MARS SEEN IN GREAT GREENWICH TELESCOPE

The *Syrtis Major* (extreme left) is cut in two by a white cloud The very wide canal, *Gehon*, runs downwards, and in order from it to the left are the canals *Hiddekel*, *Euphrates*, and *Phison*

The *canali* in the *seas* are continuous with those in the *continents* They show a marked preference for entering or leaving the *seas* at a *bay* or *gulf* rather than at a point where the *coast* is straight, thus indicating that their distribution is in some way dependent on the configuration of the *seas* Their arrangement *inter se* is also remarkable not only do three or more tend to intersect at a single point, but each one, after leaving the point of intersection tends to connect with another similar point of intersection several hundred miles away They may, in fact, be likened to the railway tracks upon a map, passing from one great junction to another

The changes in the *canali* appear to be similar to those in the *seas*, being probably both seasonal and irregular In addition, certain of the *canali* are occasionally seen to be double

So much for what is definite , we shall now turn to that which is disputed But, before we do this, let us understand precisely wherein the dispute lies It is not, as often supposed, primarily concerned with their artificiality , it is rather a question of their appearance, whether or not it is of a geometrical character At the one extreme Lowell drew them as perfectly geometrical straight lines, while at the other M Antoniadi represents them as diffuse, irregular, and discontinuous markings The reason for these great diversities is three-fold variations in the degree of the perfection of the atmosphere , differences in the apertures of the telescopes used , and idiosyncrasies of different eyes in the interpretation of delicate detail It might be thought that most reliance should be placed upon the largest telescope , but this is only true up to a point For the larger the telescope the more perfect must be the atmosphere , under indifferent atmospheric conditions the smaller telescope will often show more

Lowell found that as the air improved the geometrical character of the *canali* grew more and more apparent Now, although his atmosphere is the best in the world, he was seldom able to make

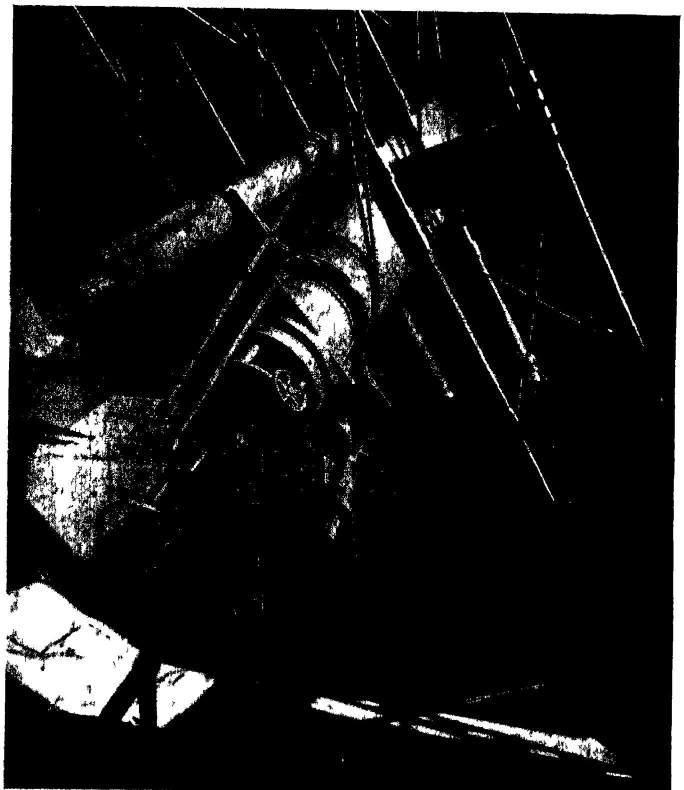


Photo by Dr Steavenson] [*By permission of the Astronomer Royal*

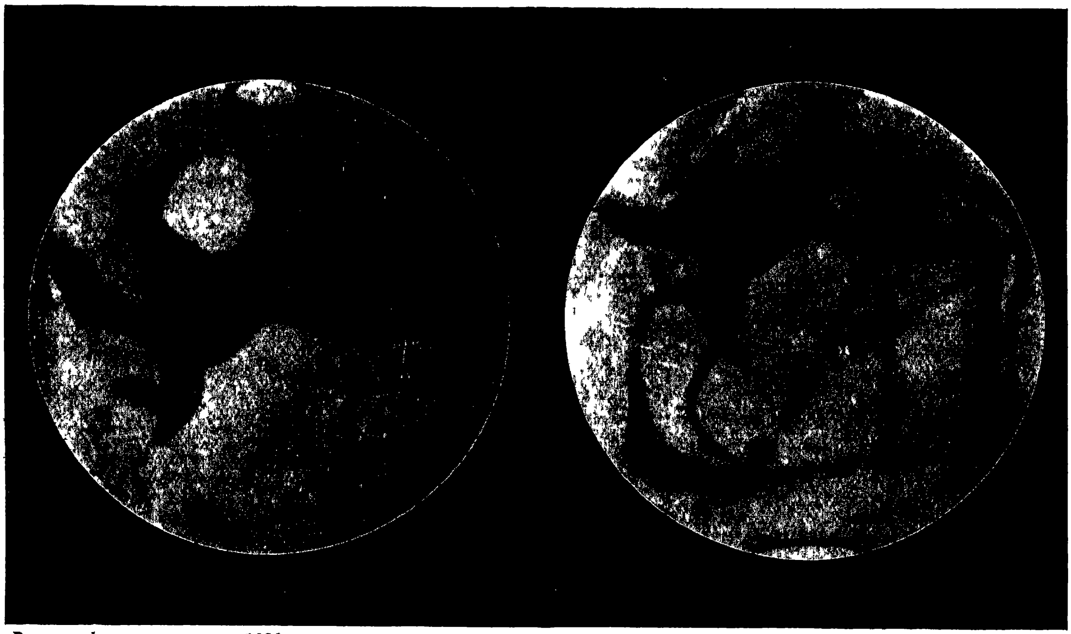
THE TWENTY-EIGHT INCH TELESCOPE AT GREENWICH

Some astronomers maintain that the canals only appear straight and regular in comparatively small telescopes, and that larger ones show them as irregular markings Yet Dr Steavenson has seen them as apparently continuous streaks with this great telescope

use of the full twenty-four inches of the aperture of his telescope He generally reduced it to twelve or fifteen inches, and, even under the best conditions, got no advantage by using more than twenty inches

M Antoniadi, using the thirty-three inch telescope at Meudon, Paris, finds, *when the air is poor*, that the *canali* resemble Lowell's drawings, and suggests that this explains his geometrical representation of them On the other hand, most observers find that poor air renders detail more diffuse—*never* sharper M Antoniadi believes that the complex detail revealed by the great French telescope might well assume a garb of regularity when seen with the smaller telescope of the Lowell Observatory In reply to this, the supporters of Lowell declare that the Meudon telescope is larger than the condition of the air permits, and therefore gives a diffuse, discontinuous appearance to what are really fine lines

The majority of observers lie intermediate between these two extremes The drawings of the



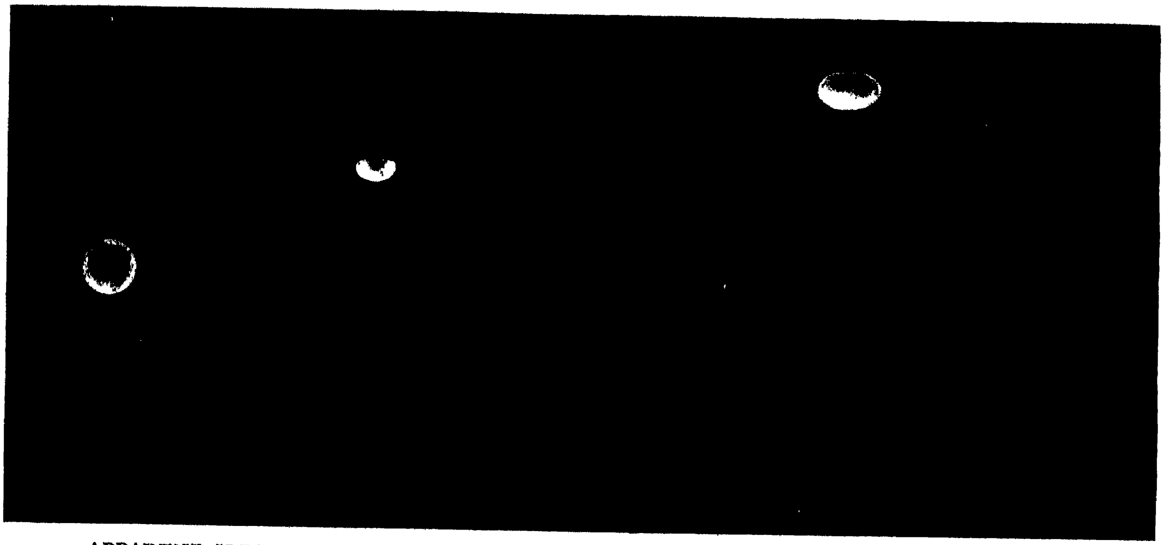
Drawings by] 1900 1922 [*Dr Steavenson*

CHANGES ON MARS

These two drawings were made by Dr Steavenson in 1909 and 1922 and illustrate certain interesting changes The tip of *Syrtis Major* (left) is pointed in 1909 and square in 1922 The " Forked Bay " (right) is much darker in 1922, while *Pandorae Fretum*, the dark horizontal band above it, is narrower and fainter Running upwards at right angles to this last and forming the right border of the round white area *Hellas*, is *Hellespontus*, which is darker in 1922 In 1909 the south pole, in 1922 the north pole is tilted towards us

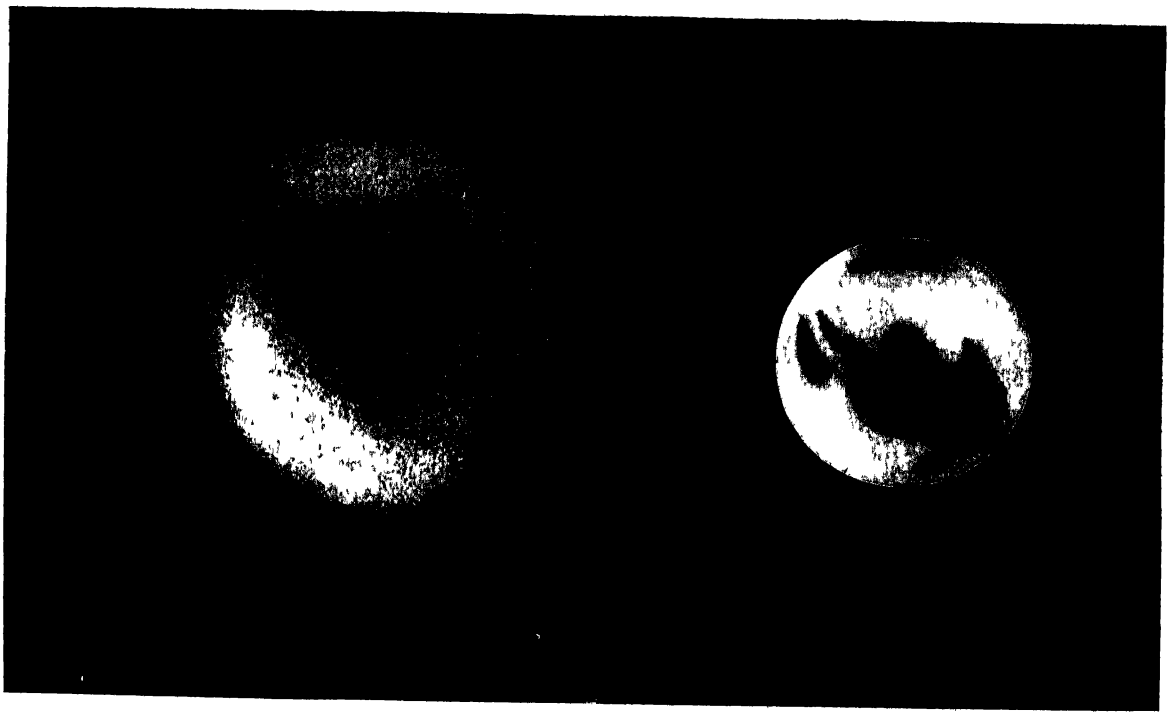
canali by the other observers at Flagstaff differ only in their narrowness from those of Lowell—although somewhat wider, they are perfectly straight and regular Professor Pickering's drawings differ in the same way In England, the Rev T E R Phillips, Dr Steavenson, Mr H Thomson, and Mr Stanley Williams draw them still wider, yet, nevertheless, straight and regular, at the same time, fully realising the limitations of their atmosphere, these astronomers do not lay any great stress on their results The drawings of Molesworth, in Ceylon, closely resembled those of the English observers But probably those favoured with the best atmospheric conditions after Flagstaff are M Jarry Desloges and his assistants MM G and V Fournier Their drawings bear a close resemblance to those of Lowell and his assistants They find that, although the majority of *canali* are wider than Lowell drew them, a small percentage are quite as narrow It thus appears that the straightness and regularity of the *canali* are generally agreed upon only their degree of narrowness is disputed

Now although the wider lines, that are generally accepted, do not have that undeniable appearance of artificiality presented by the finer lines of Lowell, they do, nevertheless, have a decidedly unnatural appearance. Their length, their straightness, and the fact that several of them intersect at a single



APPARENT SIZE OF MARS AT GREATEST, MEAN, AND LEAST DISTANCES FROM EARTH

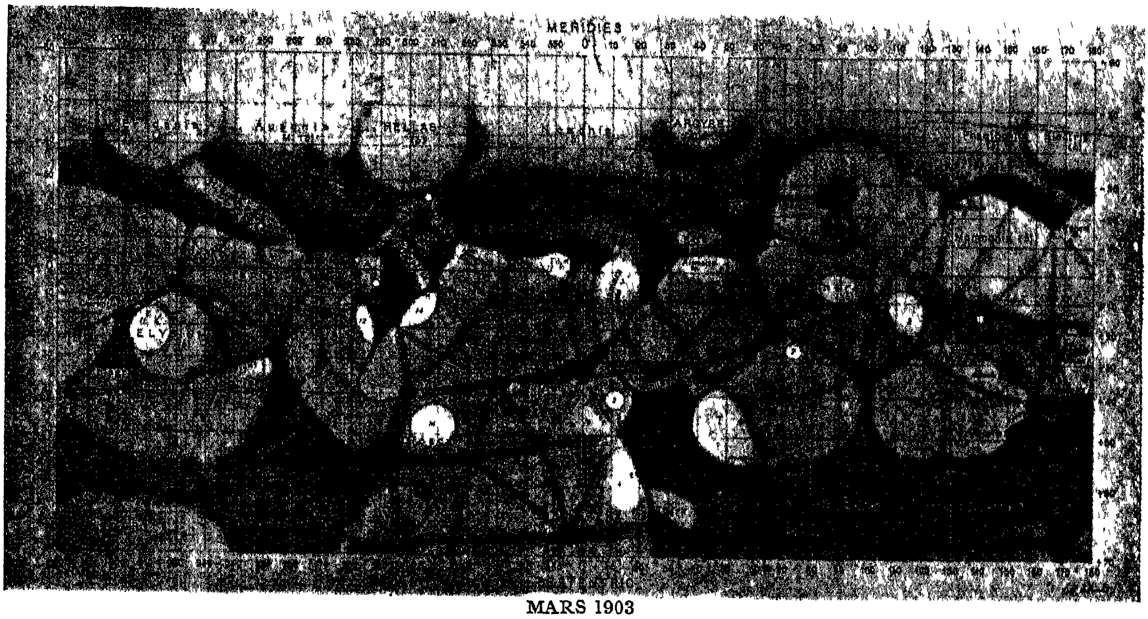
At its greatest distance Mars is on the far side of the Sun from the Earth at a distance which may reach nearly 250 million miles. At its nearest it appears seven times as large—as big as a halfpenny at 200 yards distance. It is then thirty-five million miles from the Earth



RELATIVE SIZES OF EARTH AND MARS

The diameter of Mars is 4,215 miles, which is roughly half that of the Earth. The surface of Mars is but a quarter of that of the Earth and its volume one eighth of the Earth. Its weight is one-ninth, and gravity at its surface is one-third. A weight of nine stone on the Earth only weighs three stone on Mars

point render the theories that they are river valleys or mountain chains well-nigh impossible Probably the most plausible natural explanation is that they are cracks in the surface produced by volcanic action On this hypothesis we could account for their straightness and their radiation from single points Their great length, however, is a difficulty, while their tendency, after radiating from one point, to connect with a *second* point of radiation is an objection practically insurmountable Its



MARS 1903

MARS 1916

By permission of] [*British Astronomical Association*

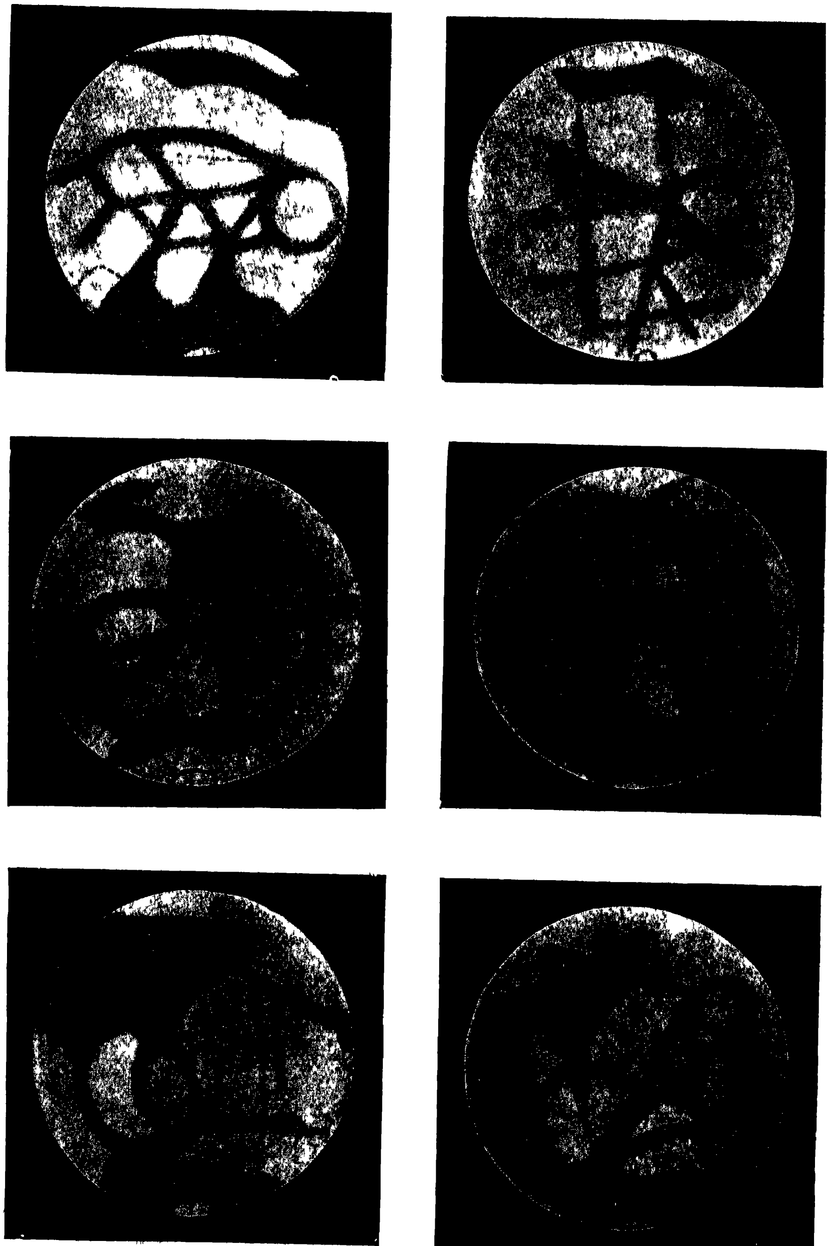
CHARTS OF MARS

These two charts, made at intervals of thirteen years, were made from the combined observations of the members of the Mars Section of the British Astronomical Association In 1903 the approach of Mars to the Earth occurred at the end of March, in 1916 in the middle of February, so that neither approaches were very close ones It will be seen that these observers draw the canals far less narrow and distinct than M Jarry Desloges or some of the American astronomers The white areas seen in the upper chart are interesting it has been suggested that some of the smallest of these, which are intensely white, and generally seen in the *summer* and *near to the equator*, are crops !

happening in one case might be explained as a curious coincidence, but the large number of examples actually presented would, on this hypothesis, be so improbable as to be outside the limits of possibility

An attempt has been made to get round the difficulty of finding a natural explanation of the *canali* as they appear to us, by assuming that this appearance is totally different from that which they would present if seen close to In this connexion experiments were made by Mr Evans and Mr Maunder which showed that a seemingly haphazard distribution of spots may give rise, at a distance, to the appearance of geometrical straight lines (*see* page 24) But such a distribution cannot be entirely at random, there must be some underlying method in the arrangement if the geometrical effect is to be produced Moreover, that method in arrangement must be fairly well marked, otherwise the geometrical lines seen by one observer would be different from those seen by another, and would vary for the *same* observer according as the distance of the planet changed or the magnifying power of the telescope was altered The suggestion, therefore, is by no means so convincing as it might at first sight appear At most, it merely shows that the *canali may* not be geometrical lines, it does not *prove* (as some seem to think) that they *cannot* be geometrical lines

Lowell believed that the *canali* are strips of vegetation growing upon the banks of artificial waterways or "canals," which have been constructed by

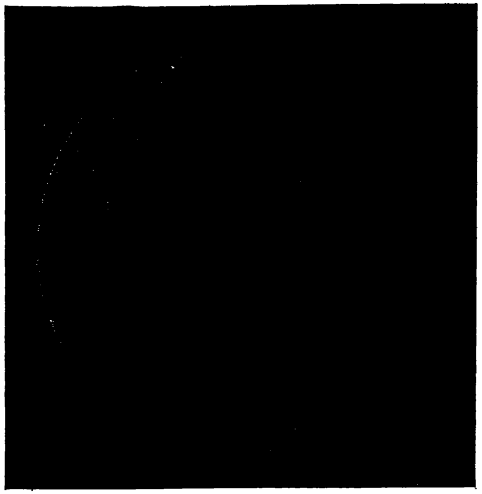


W H Pickering *A E Douglass*

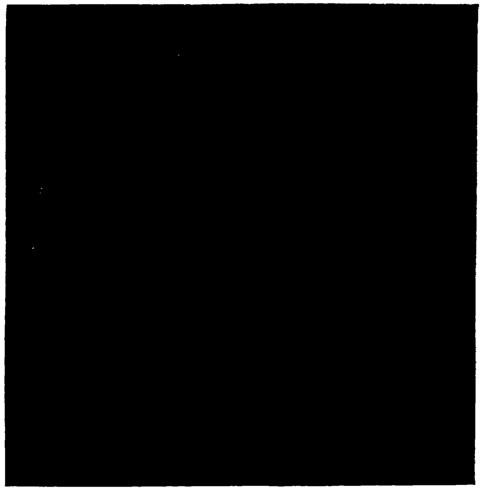
[*From "Popular Astronomy"*

MARS IN 1920

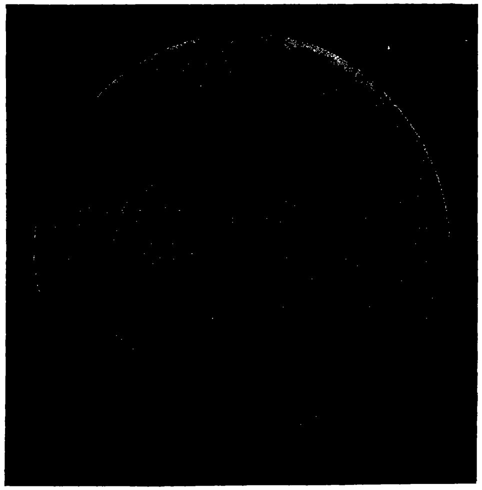
The drawings on the left are by Prof Pickering with an eleven inch telescope in Jamaica, those on the right by Prof Douglass at Tucson in Arizona The drawings of each pair (right and left) are of the *same* aspect of Mars, and illustrate the way in which two observers differ from each other in drawing the same thing It will be seen that Prof Pickering's canals are wider and less regular than those of Prof Douglass. The lower end of the *Syrtis Major* (lowest pair) presented a curious form in 1920, and *Nepenthes-Thoth* was very dark



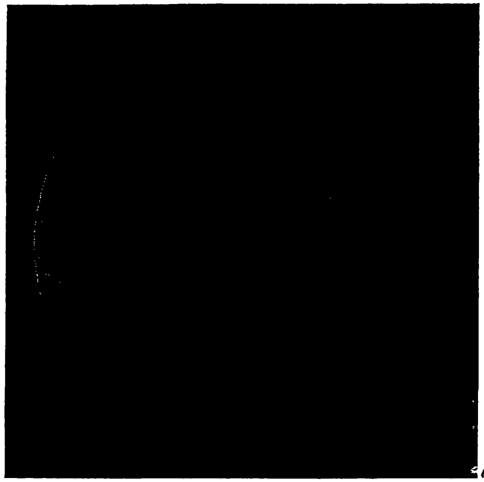
April 25



March 9



March 1



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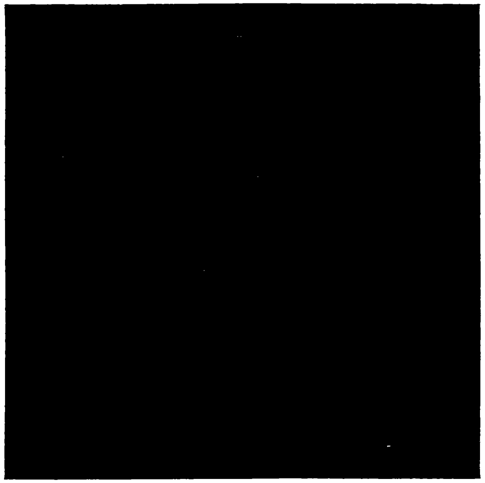
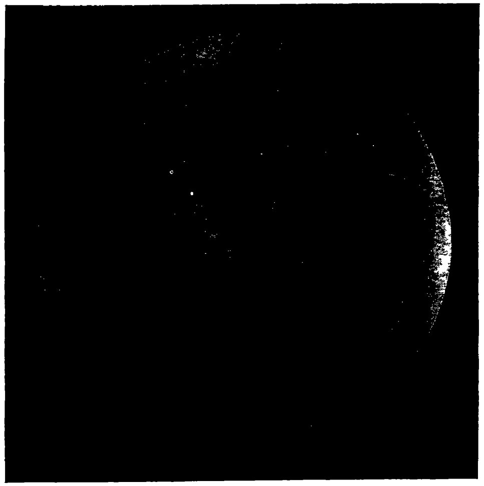


March 23



March 21

[*Drawings by*] [*Rev T E R Phillips*

MARS 1918—PHILLIPS

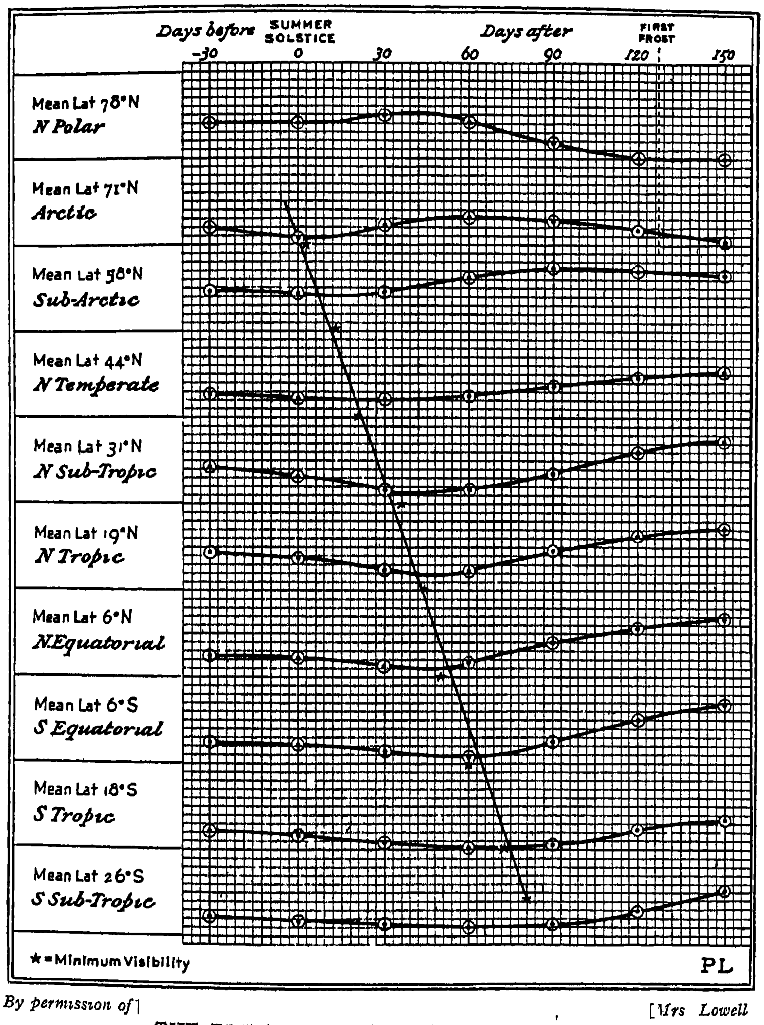
These beautiful drawings are arranged to show different aspects of the planet in their right order In the first the "Forked Bay" and *Margaritifer Sinus* are on the right, and *Mare Acidalium* below In the second Margaritifer S and M Acidalium are on left, and Aurorae Sinus is above In the fourth and fifth the brilliant white area is *Elysium*, bordered above by the dark *Cerberus* In the fifth again and in the last is *Syrtis Major* with *Nepenthes-Thoth*, very wide, and *Nilo-Syrtis*, two canals issuing from its left side and lower extremity respectively A curious cloud or mist is seen near the north pole and also in the neighbourhood of the *Syrtis Major* The two canals "sprouting" from the right of the *Syrtis*, *Astaboras* and *Astusapes*, are in some years invisible

intelligent beings He pointed out that this theory accounted for the straightness of the *canali*, their great length, their network arrangement, the manner in which they emanate from the *bays* and *gulfs* upon the *coast*, and for their changes being largely seasonal In addition, he urged that the conditions existing upon the planet were not incompatible with intelligent life, and that if such an intelligence did indeed flourish it was to be expected that its whole energy would be directed towards the problem of making the best use of the planet's extremely small water supply of conveying the water from the melting snows into the fertile regions and onwards across the deserts The duplication of the *canali* he explained as the outcome of a further perfection of this irrigation system, by which the water, after fertilising the banks of one canal, was pumped through transverse channels into a second parallel canal to be used over again

This explanation seems to account for everything , there are no *really* insurmountable difficulties to be brought against it It must, however, be remembered *that a theory which postulates intelligent existence will*, ipso facto, *account for practically any phenomenon* That it fulfils this purpose is no proof of its truth , other evidence must be forthcoming before we can accept it If Lowell's drawings and observations were accepted in their entirety, they themselves would probably be sufficient evidence For it seems that no natural theory is compatible with them , nor yet do they admit of Mr Maunder's explanation, for the better the atmospheric conditions the *sharper* did they appear to Lowell—they were never resolved by him into complex, discontinuous markings But we must take as our criterion the observations of the *majority*, and their evidence is *not* conclusive In summing up, therefore, we must say that, although we have found no satisfactory natural explanation of the *canali*, we have no proof of their artificiality Until that proof is forthcoming we have not the least right to assume the existence of intelligence

* * *

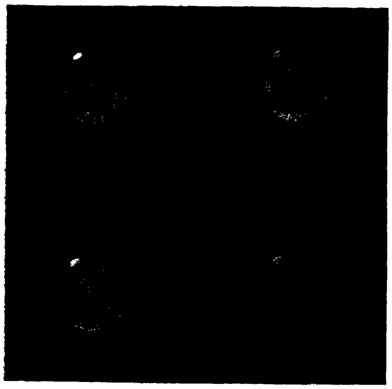
In the year 1877, Professor Asaph Hall discovered with the twenty-six-inch telescope at Washington, two minute moons



By permission of] [*Mrs Lowell*

THE DEVELOPMENT OF CANALS—LOWELL

These ten curves represent the variations in the darkness of the canals a rise in the curve indicates darkening, a fall a fading Ten zones of latitude have been chosen at varying distances from the melting north pole , each of these is represented by a curve The lowest point of each curve represents the time at which the canals of that zone *begin* to darken The straight line joining these points shows that it occurs a greater number of days after Martian midsummer as one gets farther from the melting pole The beginning of darkening of a canal is believed to represent the first growth of vegetation on its banks



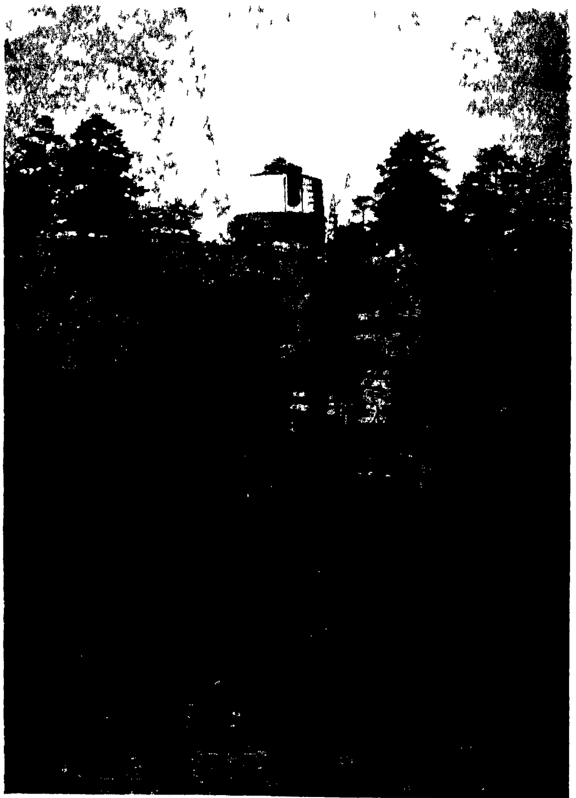
No 1
Barnard
Forty inch Telescope, Yerkes
PHOTOGRAPHS OF MARS, 1909
It was once hoped that the canal dispute would be settled by photography So far that has not been realised The eye is able to catch instantaneous glimpses of very delicate detail during the extremely short periods of steady air But a photographic plate must record steady and unsteady periods indiscriminately—

No 2
Hale
Sixty inch Telescope, Mt Wilson
PHOTOGRAPHS OF MARS, 1909
so that the finest detail is blurred Again, the grain of the plate is coarser than the image of most of the canals The original negatives of the most recent photographs at Flagstaff show many canals when minutely examined, but they do not permit of reproduction

in attendance on Mars The nearer one, *Phobos*, is 5,800 miles from the centre of the planet and, therefore, only 3,700 miles from its surface It revolves round Mars in *seven hours thirty-nine minutes*—less than one-third of a Martian day In this respect it is unique, for we know of no other body which revolves round its "primary" in a period shorter than that of the rotation of the "primary" upon its axis It is, therefore, most interesting to note that, more than one hundred years before Professor Hall's discovery, Dean Swift, in his "Gulliver's Travels," tells of the detection, by the astronomers of a fictitious race, of two satellites of Mars, one of which possessed this very unprecedented property! To an inhabitant on Mars, *Phobos*, unlike all other heavenly bodies, rises in the *west*, travels quickly across the sky, and sets, four hours later, in the *east*, changing in that short time from new to full moon, or from full to new moon

The outer satellite, *Deimos*, is scarcely less unconventional At a distance of 14,600 miles it moves round the planet in *thirty hours eighteen minutes* Since this period is not very much longer than that of Mars' rotation, *Deimos* remains above the Martian horizon for nearly *three days without setting*, and during that time goes through all its phases (from new to full moon) twice over

On the assumption that their surfaces are, area for area, of the same brightness as that of Mars, these bodies are less than twenty miles in diameter As moons in the Martian sky they can serve no useful purpose, for they do not, like our Moon, give any adequate light in the night season To one standing upon the equator of Mars, *Phobos* gives but *one-sixtieth* part of the light of our own Full Moon, while *Deimos* gives only *one-twelve-hundredth* part But much of the Martian surface is at a still



By permission of] [*Mrs Lowell*

MARS HILL, THE LOWELL OBSERVATORY
This observatory stands at an altitude of 7,250 feet In addition to the twenty four inch refracting telescope, the dome of which is seen in the picture, there is a forty-inch reflecting telescope and other smaller instruments

greater disadvantage, for in those latitudes which are higher than sixty-nine degrees north or south of the equator, *Phobos*, the brighter moon, never comes above the horizon As seen from the Earth, these bodies appear no brighter than does a man's hand held in the sunlight at a distance of one hundred miles !

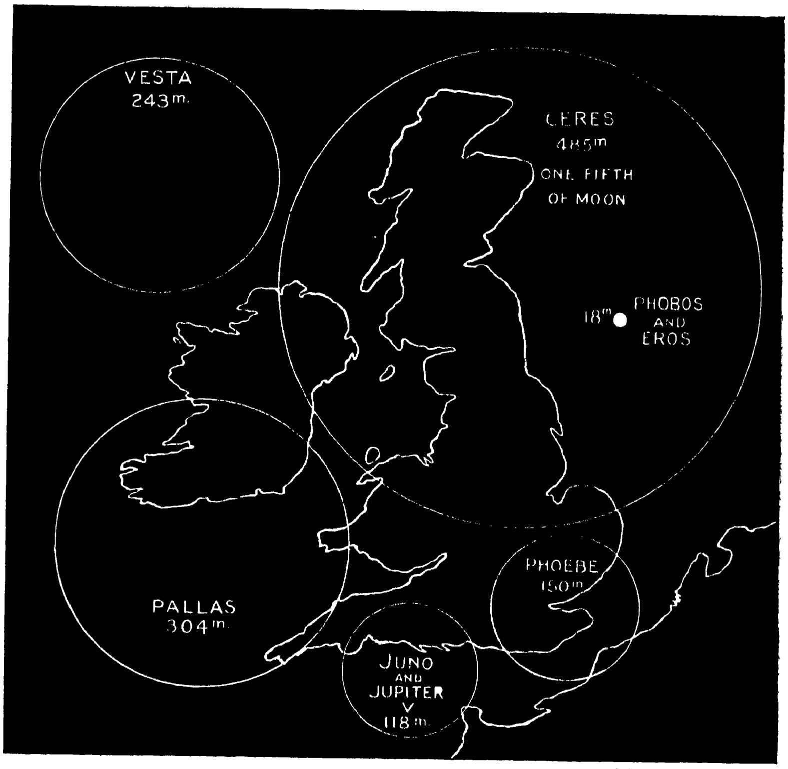
* * * * * * * *

We now leave the planet Mars and its moons We shall take away with us the memory of some things seen certainly mists and clouds, snow, water, vegetation and deserts But there is something else that we cannot forget, a something seen as through a glass darkly For outlined upon the sand of the desert and stretching away into the regions of fertility we have found strange tracks—the footprints, may be, of an unknown intelligence

THE ASTEROIDS OR MINOR PLANETS

By A C D Crommelin, B A, D Sc, F R A S

The asteroids cannot be said to possess any telescopic interest The four largest, Ceres, Pallas, Juno, and Vesta, are the only ones that show measurable discs, even in large telescopes, the others appear simply star-like points (hence the name "asteroids"), and the only feature that calls for remark in their aspect is the variation of brightness that many of them exhibit, from which it may be inferred (see page 324) that they are of irregular shape The interest that they do possess, and it is a very considerable one, is in the support that they give to the theory that the matter now embodied in the great planets was once scattered, in the form of small particles, through large regions of the Solar System In the unique case of the asteroids a ring of numerous tiny bodies was formed, instead of a single planet The earliest view, formed when only a few members of the family were known, was that a planet had exploded, and separated into several fragments, their orbits being rendered slightly different by the force of the explosion



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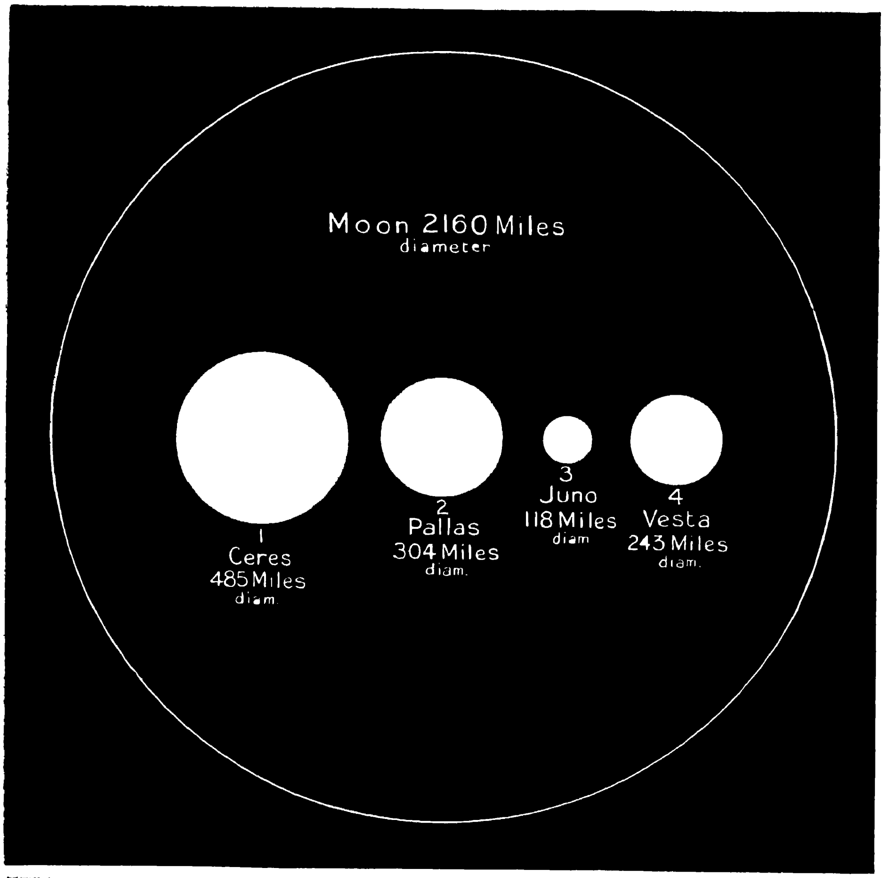
ASTEROIDS COMPARED WITH THE BRITISH ISLES

The sizes of the four brightest asteroids are shown on a map of the British Isles The diameter of Ceres, the largest, is equal to the length of England from Land's End to Berwick. It needs a very large telescope to show them with any discs at all The sizes of Phobos, Phoebe, and Jupiter V are also shown

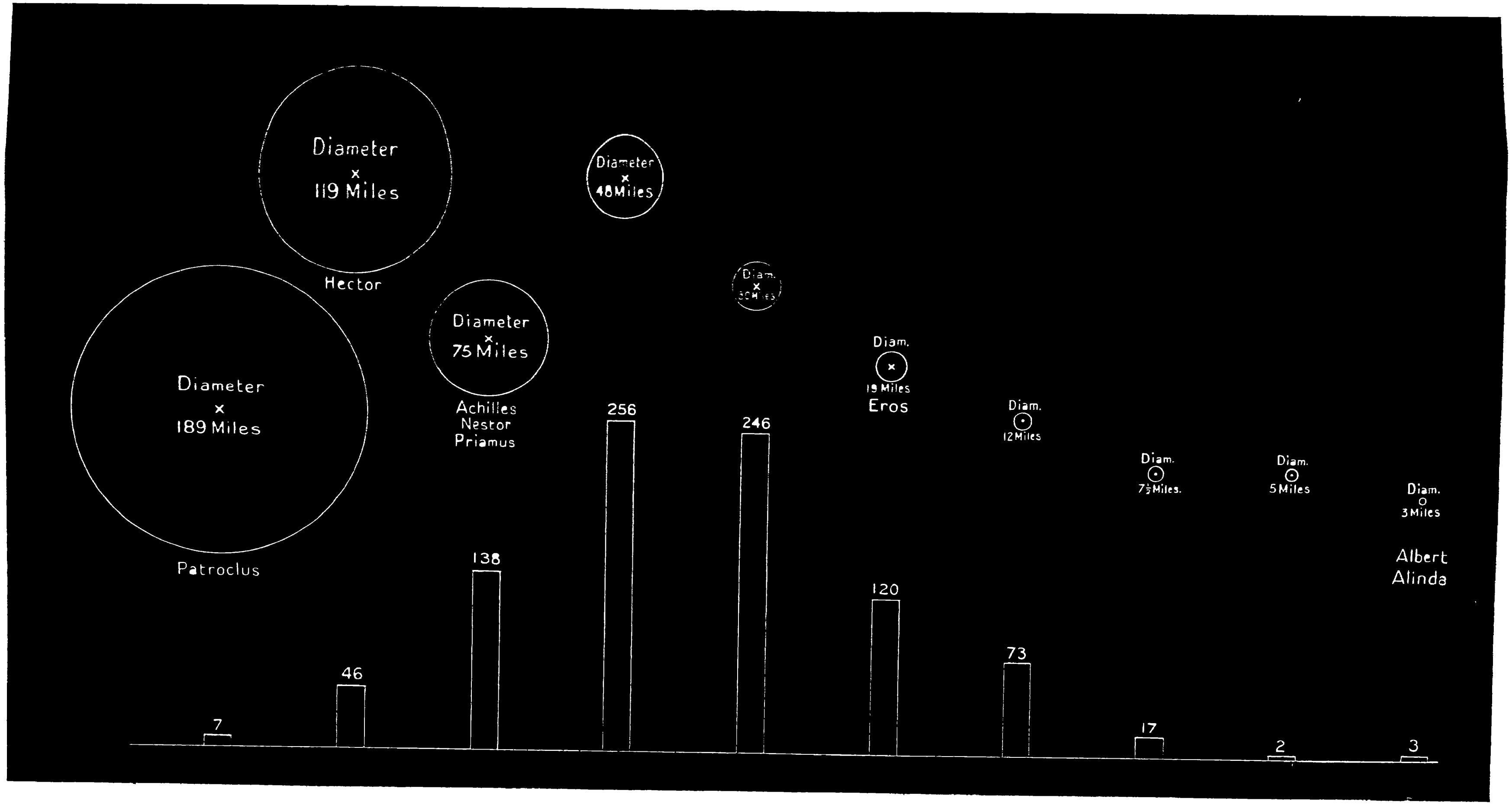
When Ceres was discovered it was noted that though its position agreed well with that predicted by Bode's Law, it was too small a body to rank with the other planets, Olbers seems from the first to have suspected that it might be one of a group of planets, so he continued the search for new bodies, being rewarded in a few months by the discovery of Pallas This new orb, still

smaller than Ceres, proved to have the same distance from the Sun as that body, which was a startling phenomenon Another surprise was afforded by the huge slope of the orbit of Pallas to the general plane of the planetary orbits Ceres had a slope of ten degrees, that of Pallas was thirty-four degrees, or more than a third of a right angle, even of the thousand orbits now known, only one or two have as great a slope as Pallas It is not surprising that the idea of an exploded planet came into vogue to explain these anomalies, and curiously enough two other little bodies were found before long in the regions specially examined, which were the crossing points of the orbit-planes of Ceres and Pallas These were named Juno and Vesta, the latter being the brightest, though not the largest of the whole family, and being at times just visible to the naked eye, since it is decidedly smaller than Ceres, it must be composed of some white substance These four bodies were assumed to complete the system, and no more were looked for till 1830, when Hencke began a search, rewarded after fifteen years by the discovery of Astraea A steady stream of discoveries then began, which was greatly accelerated in the early 'nineties by the introduction of photography as a mode of search It had previously been necessary to study the star-maps very carefully, so as to recognise any strange orb, but owing to the planet's movement a photograph showed it as a trail instead of a dot (see photograph on page 64) Needless to say, it is a huge undertaking to keep the great family of a thousand members under observation Before the war a scheme had been arranged for dividing the work among different countries The war utterly disorganised this, but things are now being adjusted again In spite of all efforts a few planets get lost Thus Aethra, discovered by Watson in 1873, was not found again till December 1922, this was in spite of frequent search, as its orbit excited special interest from its large eccentricity



THE SIZES OF THE FOUR BRIGHT ASTEROIDS COMPARED WITH THE MOON
It needed a very large telescope, the Yerkes forty inch refractor, and a skilled observer, the late Professor Barnard, to obtain reliable measures of these minute bodies Vesta, though considerably smaller than Ceres, is brighter than it, and must be formed of some white substance The sizes of the smaller asteroids cannot be measured they are simply estimated from the light that they reflect

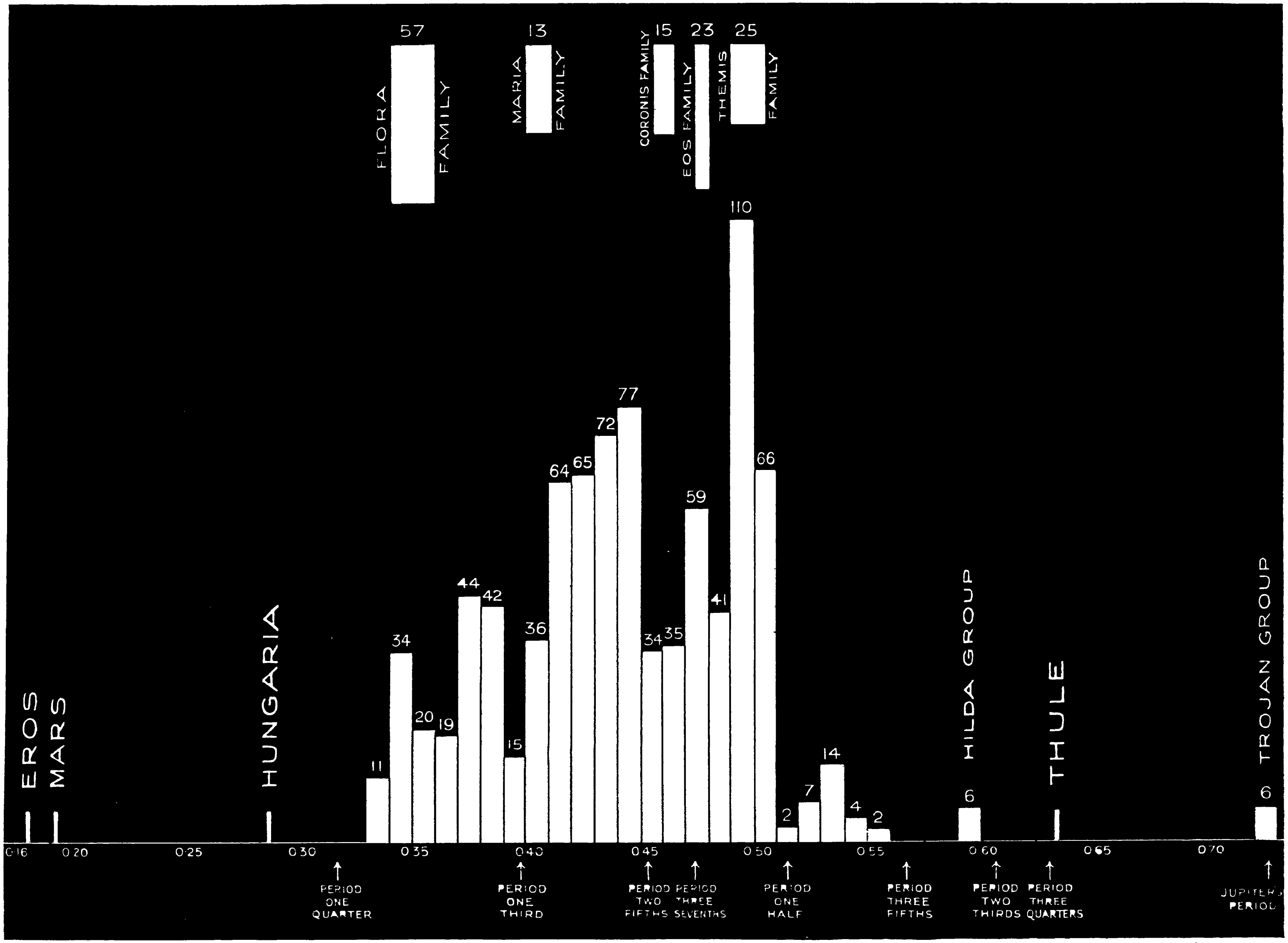
The asteroids have many analogies with Saturn's Ring In each case we have a multitude of tiny bodies prevented from uniting by the influence of a large neighbouring body, and in each case there are gaps in the ring, whose cause is seen to be perturbation The great gap in Saturn's Ring is



DIAMETERS OF ASTEROIDS

[A C D Crommelin

The asteroids (excluding the four first discovered) are here assigned to ten standard sizes The number of asteroids of each size is shown by the height of the pillar below, and given in figures also A few of the more interesting asteroids have their names inserted under the corresponding disc The combined bulk of all the asteroids known (including the four largest) is about one-twentieth of the Moon It would require nearly 100,000 asteroids of the average size now being discovered to equal the Moon's bulk The sizes are estimated from the amount of light received

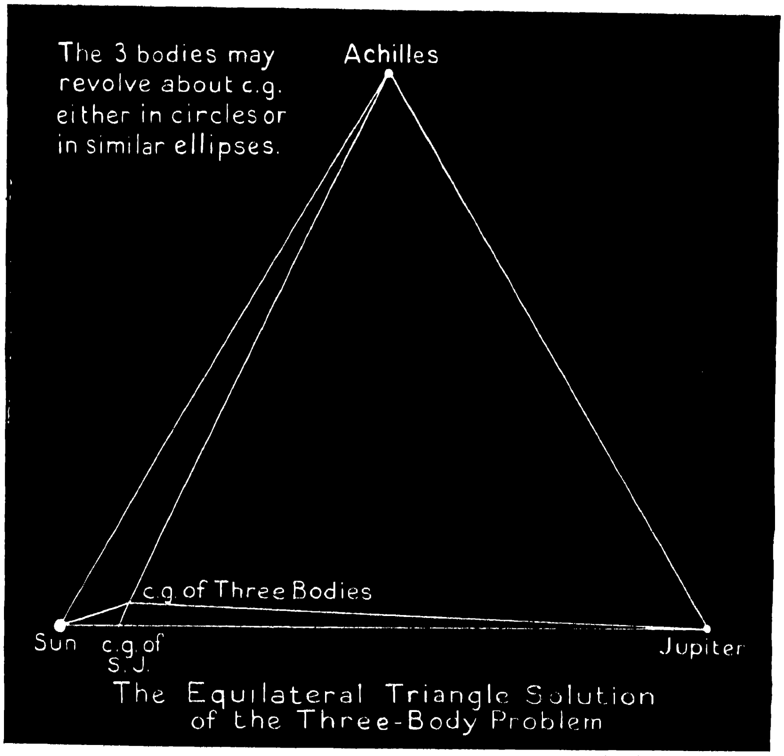


[A. C. D. Crommelin.

DISTRIBUTION OF THE ASTEROIDS AT DIFFERENT DISTANCES

[The height of each pillar shows graphically the number of asteroids at each distance from the Sun. On the whole they form a compact clump with Eros and Hungaria as inside stragglers, Thule with the Trojan and Hilda groups as outside ones. The falling off in frequency at one-half and one-third of Jupiter's period is shown. The former gap, with the densest region a little inside it, is analogous to the gap in Saturn's rings. Hirayama's five families are shown at their proper distances. They are, of course, included in the pillars below.

shown on pages 81 and 91, the latter page shows the proximity of Mimas to the ring, and, in fact, a particle in the gap would go round Saturn in just half the time that Mimas takes It has been found that when a simple relationship of this kind holds between two periods, the perturbations, being repeated in the same part of the orbit, produce a considerable change, and alter the period of the perturbed body, either temporarily or permanently A famous case is the great inequality of Jupiter and Saturn Five of Jupiter's periods are nearly equal to two of Saturn's The result is that for many centuries the period of one planet increases, while that of the other diminishes Compensation is effected after about 900 years In just the same way Jupiter affects the motion of minor planets whose periods are one-half, one-third, or other simple fractions of Jupiter's period I have prepared a diagram (page 326) which shows the distribution of asteroids at different distances from the Sun It should be explained that it is arranged by logarithms of the distances, not by the distances themselves, the tables of the asteroid orbits are arranged thus, and it would have required more time than was available to rearrange them, there are eleven asteroids whose log distance lies between 0 33 and 0 34, and so on We see that there are two outstanding asteroids, Eros and Hungaria, which lie inside the main body, the latter extends in a compact mass from the values of the logarithm 0 33 to 0 56, but the distribution is very uneven The most striking gap corresponds to period one-half of Jupiter's, while the greatest density is attained just inside this point, similarly, the brightest region of Saturn's Ring is just inside the great gap There is a marked drop in density where the period is one-third of Jupiter's, and a slight, somewhat doubtful, drop for two-fifths and three-sevenths of the period A rather unexpected feature is the group of six planets with periods two-thirds of Jupiter's, apparently this particular ratio has not the deterrent effect of the others The group is called the Hilda Group, and consists of Hilda, Ismene, Chicago, Bononia, Venusia, and Simeïsa Beyond them comes the isolated planet Thule, whose name was given (from the classical Ultima Thule) because until the discovery of the Trojan Group it was the farthest known asteroid, and has a period close to three-quarters of Jupiter's



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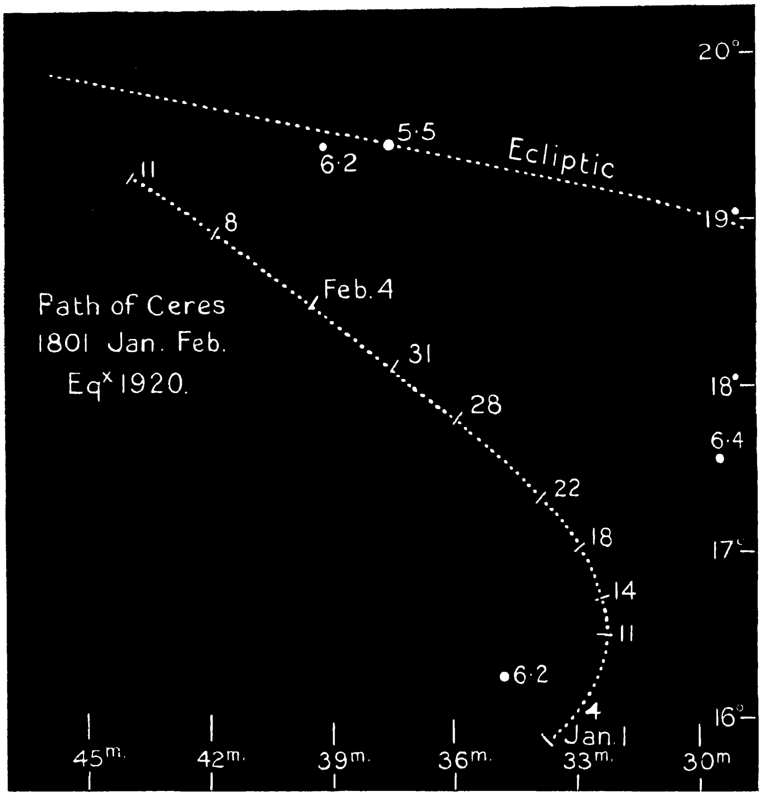
THE EQUILATERAL TRIANGLE SOLUTION OF THE THREE-BODY PROBLEM

Laplace investigated all the simple solutions of the Three-Body Problem one of them imagined the three bodies to be placed at the angles of an equilateral triangle and moving round their common centre of gravity An actual example was found in the heavens a century later The Trojan planets continually form approximate equilateral triangles with the Sun and Jupiter Four of them travel round the Sun in front of Jupiter, and two behind him The letters c g denote centre of gravity, S J Sun and Jupiter

Diagrams are also given (page 332) showing the number of asteroids with inclination and eccentricity between assigned limits The most frequently occurring values are inclination about seven and a half degrees, and eccentricity one-seventh They fall off pretty rapidly for large values, so that only three asteroids have inclination exceeding thirty degrees I have confined myself in the

above diagrams to the first 900 asteroids, the orbits of many of the others still needing further discussion

Though the idea of the whole asteroid family arising from a single exploded planet has long been abandoned, a modification of it has lately been put forward by Professor K Hirayama of Tokio He has classified all the elements of the orbits in an exhaustive manner, and applied planetary perturbations so as to obtain the "proper" or undisturbed orbits He has in this manner found five families of asteroids, each family having elements so nearly the same that a common origin may reasonably be conjectured It does not seem to me necessary to imagine that a single planet exploded to form each family The same result might be attained by supposing that they had their origin in a single condensation in the primitive dust-streams, but that this condensation had subdivided before final consolidation He gives the families the following names from the leading asteroid of each (the number of members of the family is given after the name) Themis, twenty-five members, Eos, twenty-three, Coronis, fifteen, Maria, thirteen, and Flora, fifty-seven Thus nearly a seventh of the known asteroids are comprised in these five families

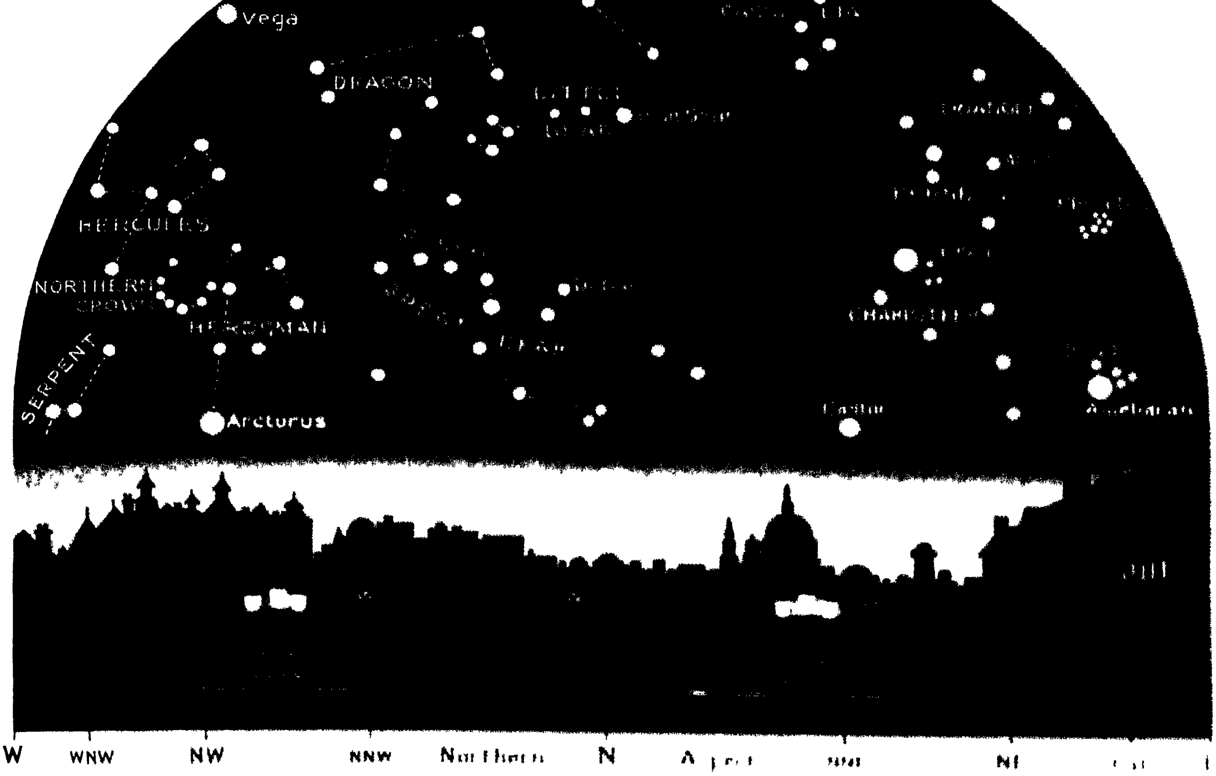


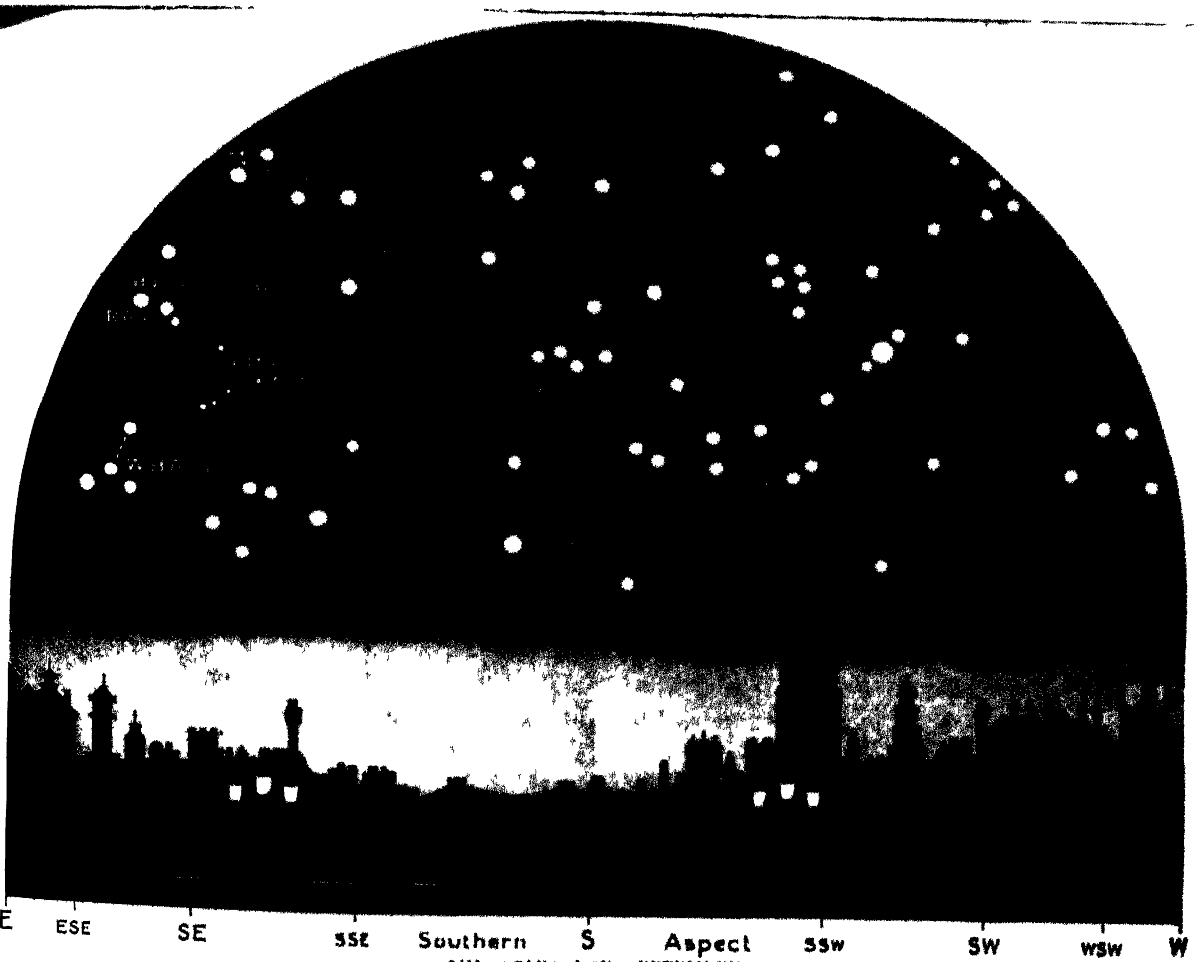
[A C D Crommelin

PATH OF CERES AT ITS DISCOVERY

When Piazzi found Ceres it was moving through the constellation of the Bull The diagram shows the positions in which he observed it The four stars shown are the only ones in the region (which is south of the Pleiades) that are visible to the naked eye

The Trojan Group deserves special mention since it realises a form of motion that was predicted by Laplace as possible a century before any actual case was known He was examining all the exact solutions that were possible of the motion of three bodies (of any assigned masses) that were moving under their common attraction, one possible solution was that the bodies were placed at the angles of an equilateral triangle, and were then projected in directions that all made the same angle with the lines joining them to their common centre of gravity, the velocity of projection of each being proportional to its distance from that centre of gravity Under these conditions it is possible to show that they will all describe similar ellipses (or other conic sections) about the centre of gravity as their focus, also that they will continually form an equilateral triangle, though this will vary in size unless the motion of each body is in a circle When Achilles, the first Trojan discovered, had been observed for a short time it was found that its distance from the Sun was nearly the same as that of Jupiter, and that it made an approximately equilateral triangle with the Sun and Jupiter It was then conjectured that Laplace's prediction had at length received a practical verification The latter is, however, not quite rigorous, for all the six Trojans that are now known have orbits that are different from Jupiter's both in inclination and eccentricity This has the result of making the motion much more complicated than the simple case imagined by Laplace





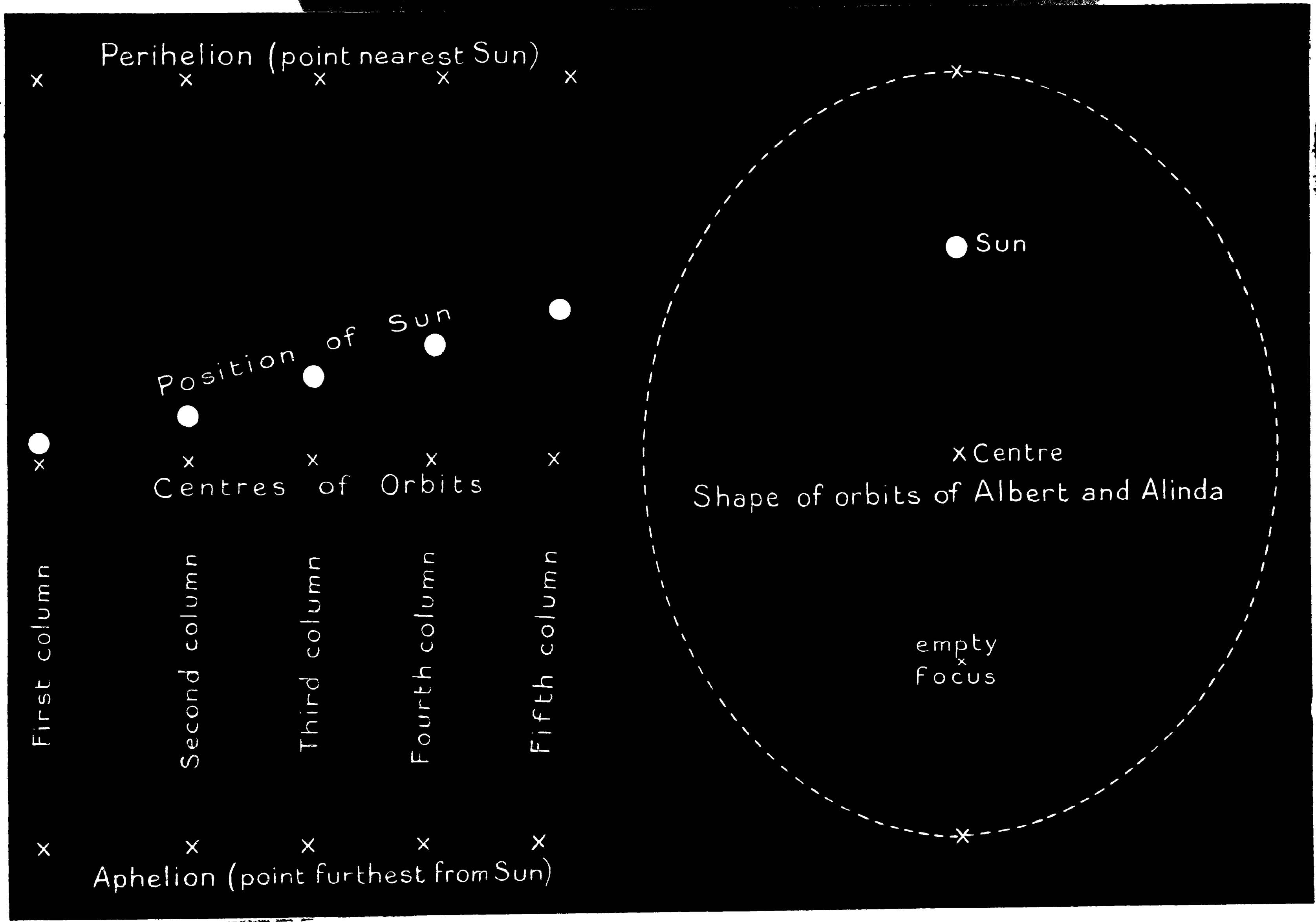
THE STARS FOR SEPTEMBER

Our plate shows the aspect of the sky as seen looking North and South from Westminster Bridge but the positions of the stars will be practically the same for any place in the latitude of Great Britain.

The constellations will appear in the positions shown on September 1 at about 11 30 p.m. (Greenwich Mean Time)

8	11 0 p.m.
15	10 30 p.m.
22	10 0 p.m.

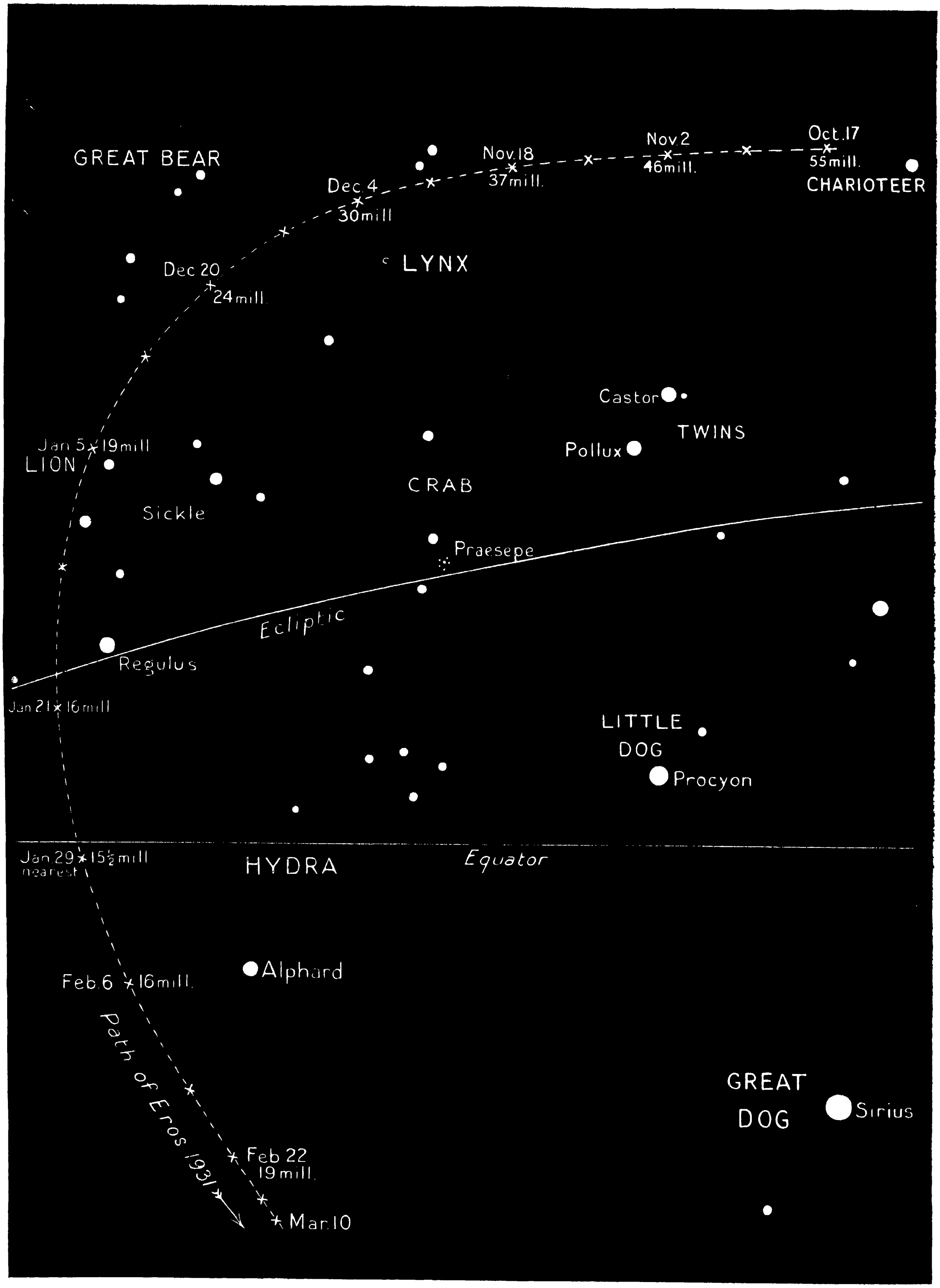
Each night the same aspect is presented four minutes earlier than on the previous night.



[A C D Crommelin

DIAGRAM ILLUSTRATING THE POSITION OF THE SUN IN ASTEROID ORBITS

The eccentricity of an orbit is measured by the distance of the Sun from the centre. When this is small the shape of the orbit is appreciably circular. But in the case of Albert and Alinda the eccentricity exceeds one-half, implying that the greatest distance of the planets from the Sun is more than three times the least distance. The orbit is here drawn in full, and differs appreciably from a circle. The columns alluded to in the diagram are those of the lower illustration on page 332



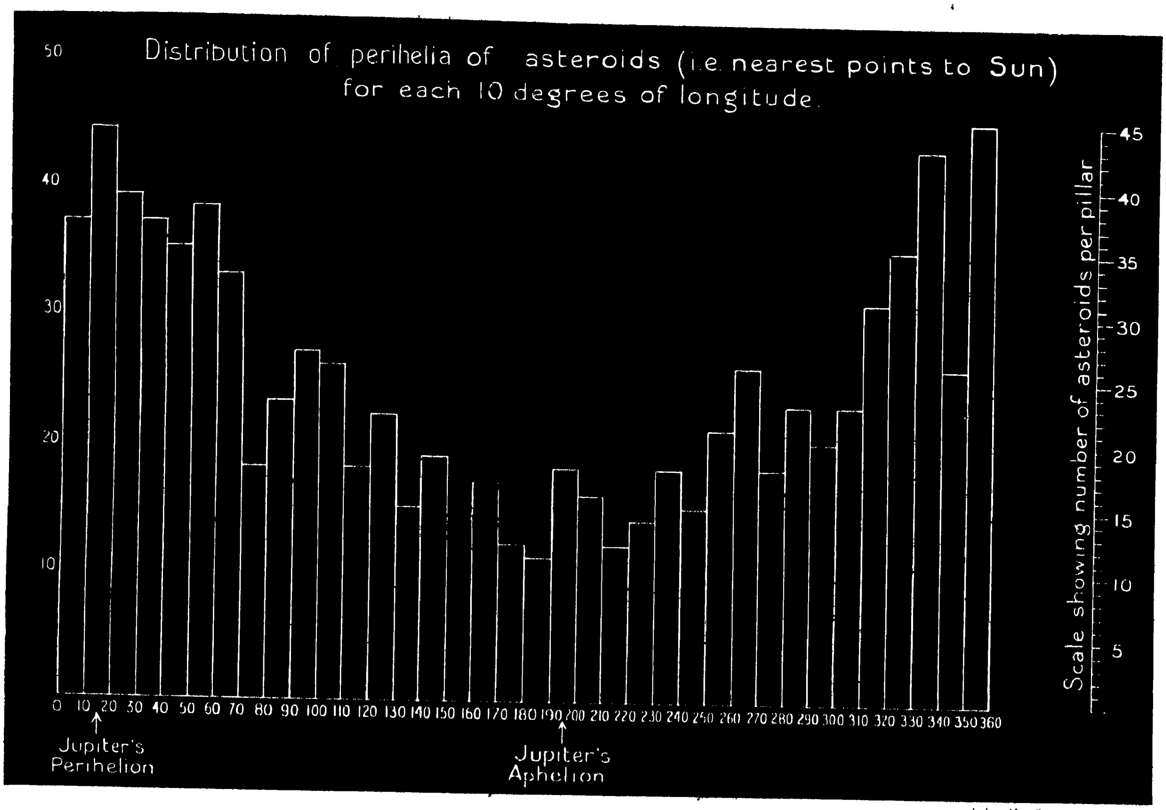
[A C D Crommelin

PATH OF EROS AT ITS NEAR APPROACH 1930–1931, AND DISTANCE IN MILLION MILES

This near approach is certain to excite great interest The least distance, fifteen and a half million miles, is little more than half that of the opposition of 1900–1901, which has hitherto been the best observed A unique opportunity will be afforded for improving our knowledge of the Sun's distance As the speed of Eros in perihelion is practically equal to that of the Earth (very slightly greater) its motion at that time appears to be at right angles to the ecliptic

However, it is found that each of the six bodies oscillates in a complicated manner about the equilateral triangle point, the periods of these swings being of the order of a century or more. One might fancy that since several asteroids have the same point as their centre of oscillation there is a danger of their colliding. The danger is very remote, since they are tiny bodies, perhaps 200 miles in diameter, and the extent of their swings (which are in different directions) is several millions of miles.

Four of the Trojans (Achilles, Hector, Nestor, and Agamemnon) are sixty degrees in front of Jupiter, while the other two (Patroclus and Priamus) are sixty degrees behind it. It is much to be regretted that the names of Trojan heroes were not given to asteroids on one side, and Greek heroes to those on the other; this would have been an aid to memory, and would have prevented the anomaly of the bosom friends Achilles and Patroclus being permanently separated by 120 degrees.

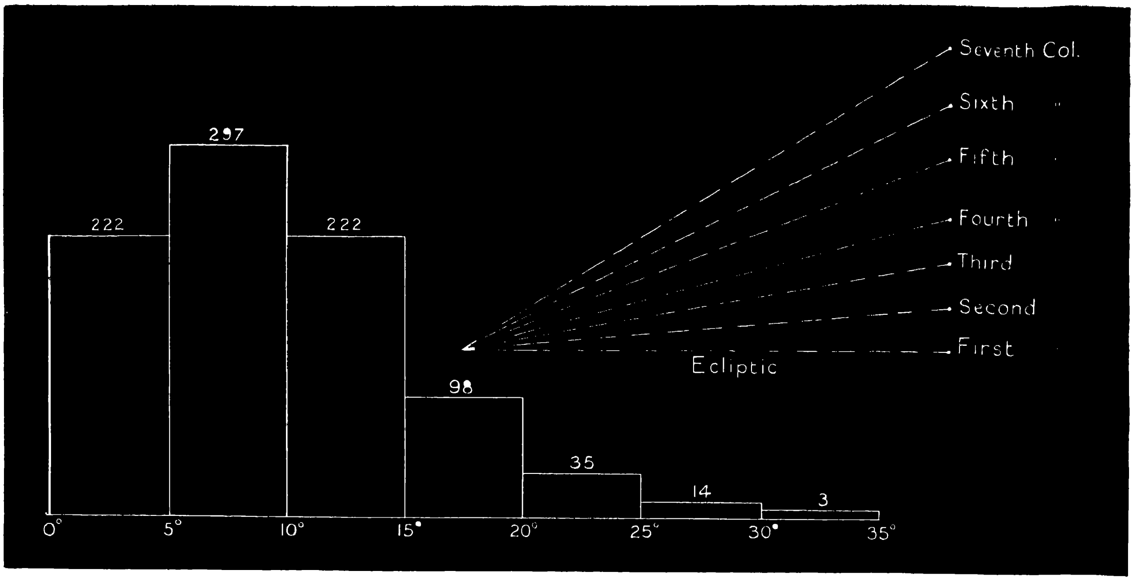


A. C. D. Crommelin

DISTRIBUTION OF PERIHELIA OF ASTEROIDS (i.e., NEAREST POINTS TO SUN) FOR EACH TEN DEGREES OF LONGITUDE

The circle round the Sun is here divided into thirty-six portions, and the number of asteroids that have their perihelia in each portion is shown by the height of the pillar. It is evident that the highest pillars come in the region of Jupiter's perihelion, and the lowest ones (one third of the height of the highest) come in the opposite region. This is a forcible illustration of Jupiter's perturbing effect on the asteroids.

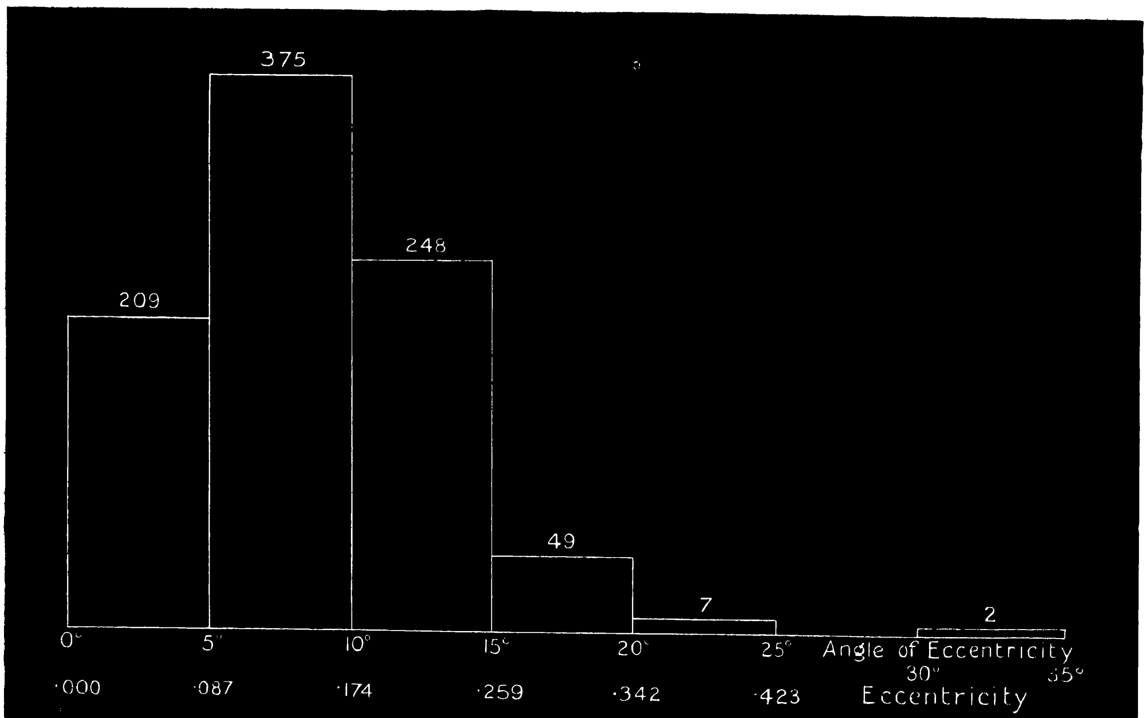
As regards the nomenclature of asteroids, the usual rule is to give them feminine names; masculine ones are reserved for planets of special interest. Besides the Trojans there are Eros and Albert, both of which approach the Earth's orbit within some fifteen million miles; the latter planet was, however, insufficiently observed, and is now lost; but another planet has been found with a similar orbit to Albert; it was given the feminine name Alinda, which is contrary to the principles laid down. It has a very eccentric orbit, its period being almost four years; it therefore goes out nearly to Jupiter's orbit, and will undergo large perturbations, the effect of which has not yet been calculated. Mention should be made of a very remarkable asteroid discovered by Dr. Baade at Hamburg two years ago. It has such an eccentric orbit that it travels all the way from the orbit of Mars to that



[*A C D Crommelin*

INCLINATION OF ORBITS OF ASTEROIDS

The heights of the pillars show the numbers of asteroids that have their inclinations between the limits noted at the foot of the pillars The inclinations are shown by the sloping lines at the side of the diagram



[*A C D Crommelin.*

ECCENTRICITY OF ORBITS OF ASTEROIDS

The heights of the pillars show the numbers of asteroids that have eccentricities between the limits noted The eccentricity for first pillar is about one twenty-fourth, for second one eighth, for third one fifth, for fourth three-tenths A companion diagram shows the position of the Sun in the orbit for each group

of Saturn, its period being about thirteen years It thus crosses the orbit of Jupiter, but fortunately for it, its orbit has a high inclination, and it does not make a very near approach to Jupiter, otherwise it would undergo huge perturbations, it has not yet been given a name, and is known simply by the number 944

A diagram is given (page 330) showing the apparent motion of Eros at the time of its near approach to the Earth in 1931 This does not claim accuracy, as the perturbations have still to be worked out It is interesting from the fact that Eros, though its orbit is outside that of the Earth, will at that time be moving more rapidly, owing to its orbit being so eccentric, it thus claims the distinction (shared with Albert and Alinda) of being in opposition without apparently moving backwards

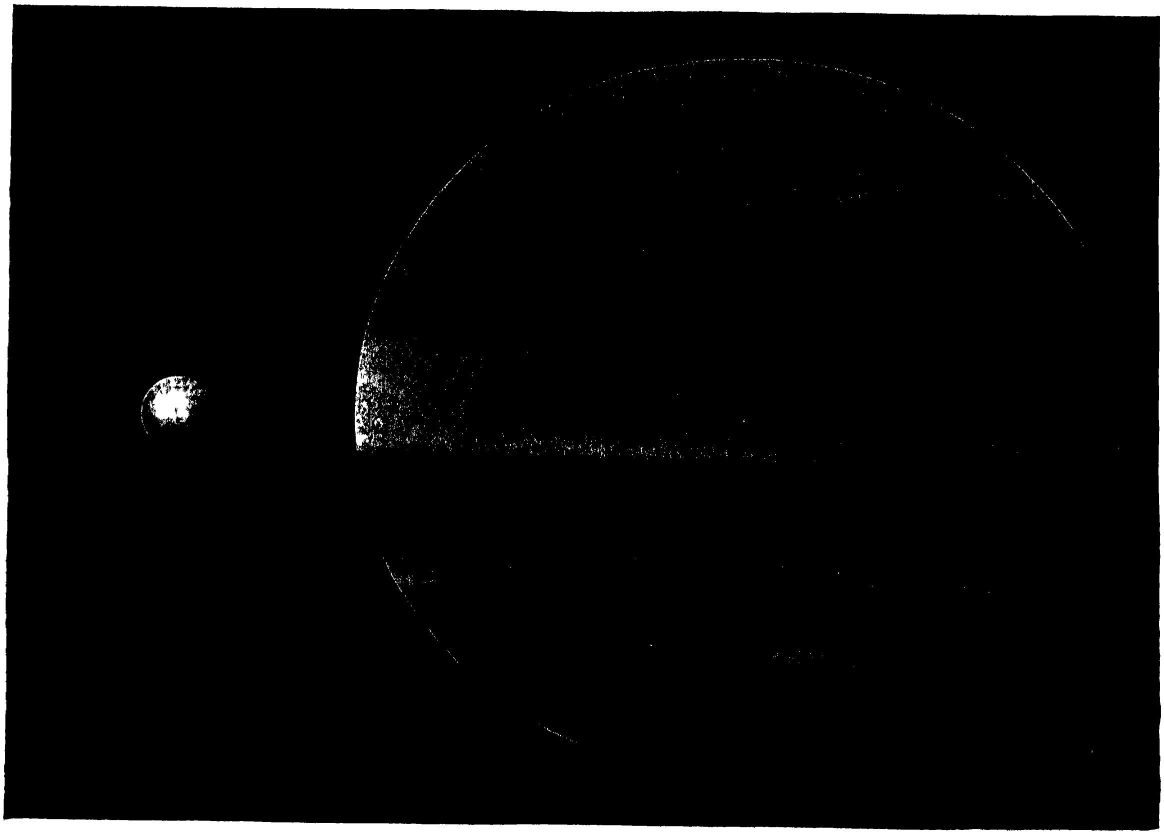
CHAPTER VIII

JUPITER

By W F Denning, F R A S

THIS planet is a magnificent object and revolves on the outer side of the great zone of minor planets distributed over a wide expanse of space exterior to Mars

He is the largest body of the Sun's attendant retinue, though he does not shine in the heavens with equal splendour to Venus, and is occasionally inferior in lustre to Mars, as in June 1922 But he presents a fine appearance nevertheless at a mean distance from the Sun of 480 millions of miles

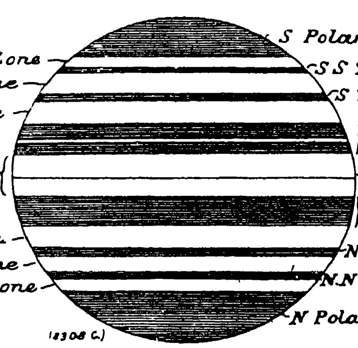


COMPARATIVE DIMENSIONS OF JUPITER AND THE EARTH

Jupiter is the largest of the planets, indeed, its bulk is greater than that of all the others combined It is between 1,300 and 1,400 times the volume of the Earth

Jupiter's equatorial diameter is 88,500 miles His sidereal period of revolution occupies 4,332 5 days or 11 86 years

That Jupiter is a giant among the planets of the Solar System will be obvious when it is stated that he is of greater mass than all the rest of them collectively. His expansive disc forms a splendid spectacle when viewed under high powers in a moderately large telescope The chief aspect of the globe is at once apparent, for a series of parallel dusky bands or belts are seen as striking features



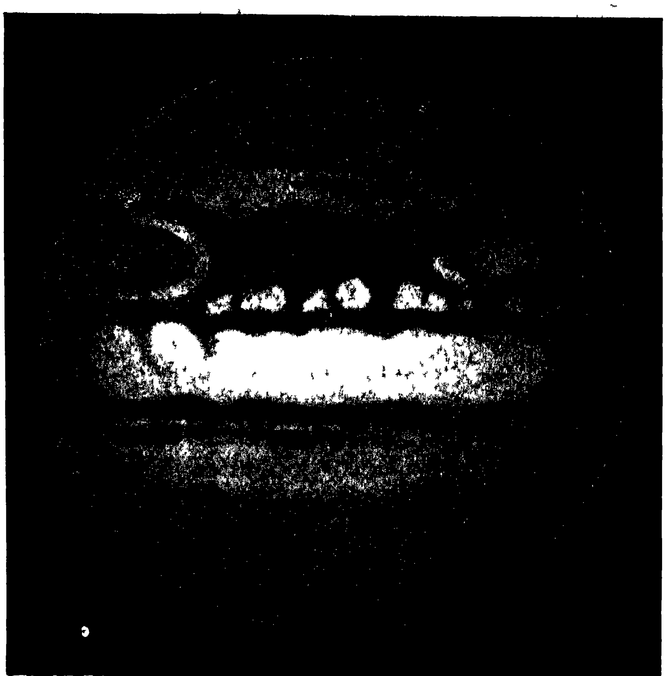
[B. A. A. Memoirs

THE ADOPTED NOMENCLATURE OF JUPITER

The diagram gives the names assigned to the different parts of the surface of Jupiter The dark streaks are known as belts, and the bright intermediate spaces as zones As the astronomical telescope gives an inverted image, the north is at the bottom of the diagram. To avoid confusion, the names of the belts are written on the right, and those of the zones on the left

Alternating with them are bright zones, and both the bright and dark regions are variegated with spots of irregular character and of different tint and magnitude These markings are clearly of atmospheric origin and situated in the outer envelope of Jupiter The real surface of the planet is not visible at all, being hidden under the dense vapours which overlie it Students of the physical appearance of this planet investigate therefore merely the outer atmosphere or envelope and its formations, changes and motions

The reflective capacity of Jupiter is relatively great, and exceeds what would have been expected In fact the planet shines with undue brightness considering his distance from the Sun It has been thought that the planet is in a heated condition, and that his physical state is in some measure responsible for his luminous aspect and active surface In the cooling process the larger planets, Jupiter and Saturn, would occupy a very long period and reach the habitable stage at a far later time than the smaller orbs, including the Earth, Venus, Mars, and Mercury These views have been held for many years without much contention, but they have now been opposed, and Dr Jeffreys has very recently investigated the question and announced his conclusions as follows "Most authorities state that the four outer planets are hot and largely gaseous The evidence available seems to me to trend in the other direction, and points to a cold surface "



Drawing by] [*E M Antoniadi*

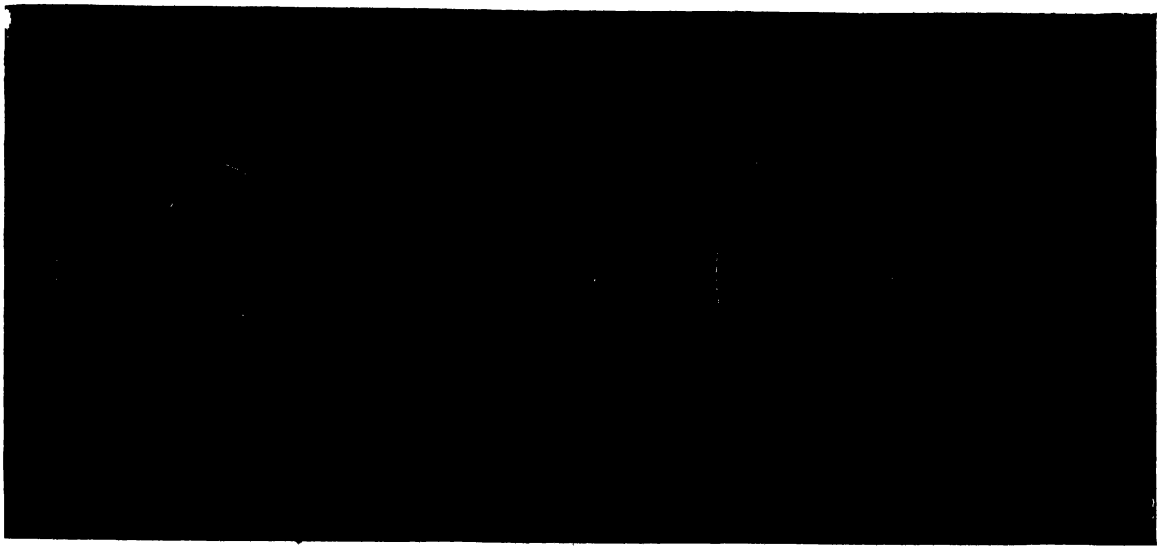
JUPITER ON 1901, MAY 21, 21h 57m

The Red Spot lying in its "hollow," is seen above the centre to the extreme left The mass of dark matter to the right of it is part of the South Tropical Disturbance, then on the same side of the globe as the Red Spot

The matter is receiving further investigation, and it is hoped that the data will enable satisfactory deductions to be made The question presents some difficulties and opinions are somewhat divided, but the subject is

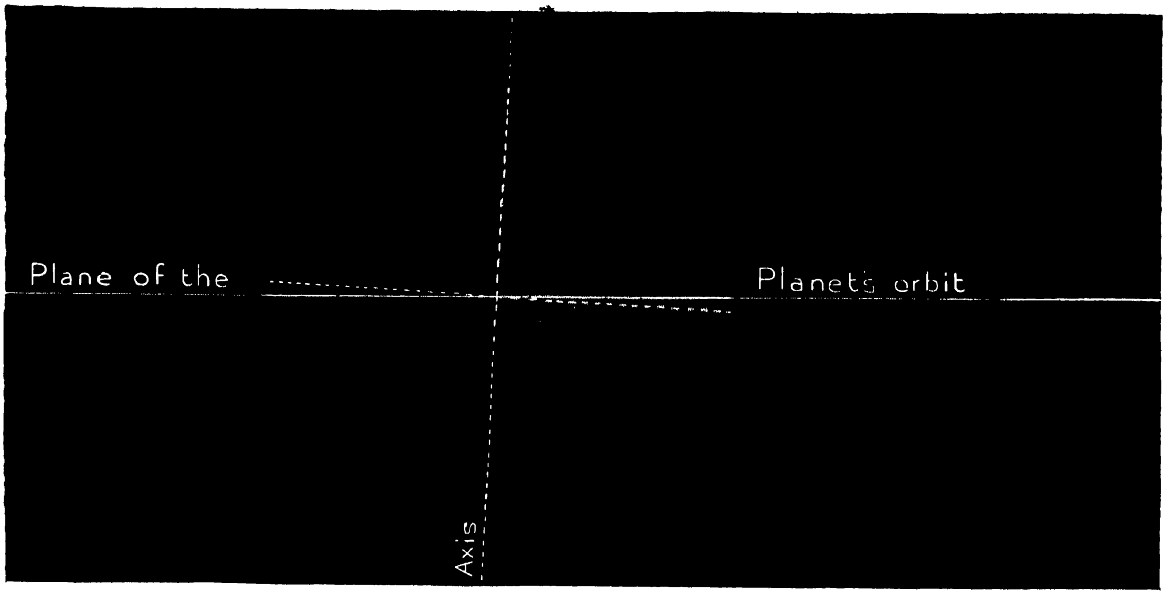
important as affecting the phenomena and condition of the large planets Old views have often had to be put on one side from the evidence furnished by later investigations, which have given us more light and shown the necessity for correction

As already stated, Jupiter is a brilliant object in the firmament when in opposition, and may easily be identified if his position is approximately known, as he shines with a very steady pale-yellow light, and is a more striking object than any of the fixed stars His place in the sky can be



VARIATIONS IN THE APPARENT SIZE OF JUPITER

When Jupiter and the Earth are on opposite sides of the Sun the distance between the two planets is at a maximum, and this distance, as compared with that at opposition, may on occasion almost reach the proportion of five to three This affects the apparent brightness of the planet in a still greater proportion—about three to one



THE TILT OF JUPITER'S AXIS

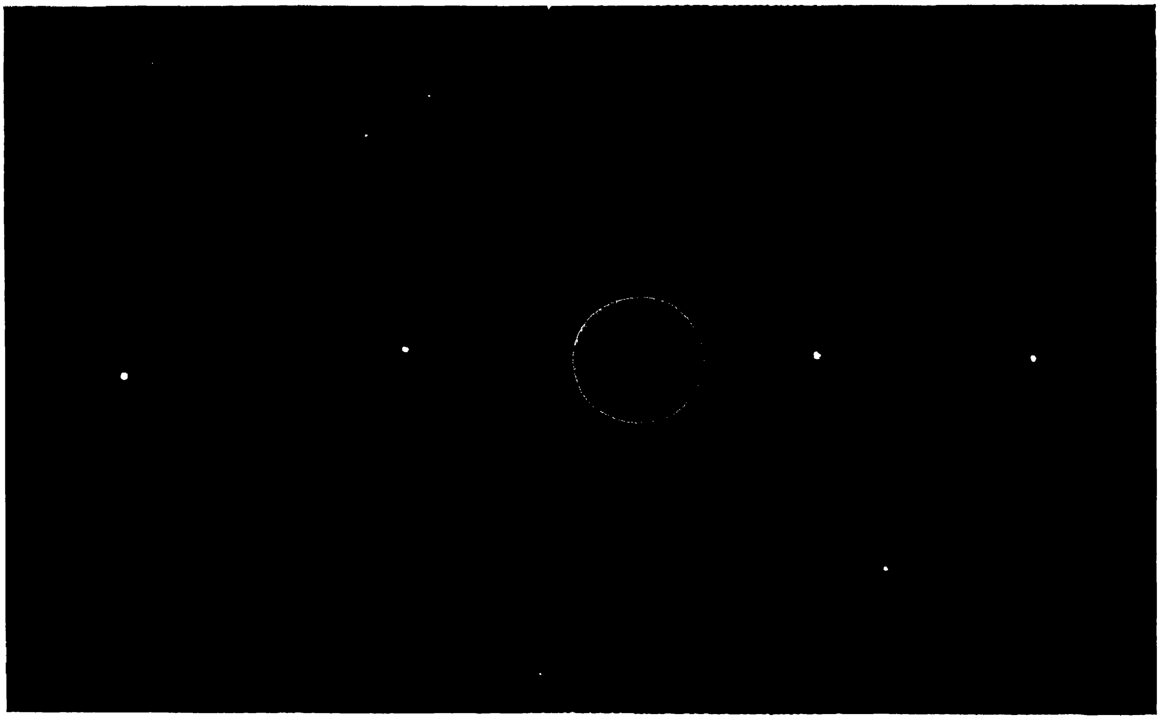
Jupiter travels round the Sun nearly "upright," the plane of his equator being inclined only about three degrees to his orbit (compare the Earth's tilt of twenty three and a half degrees) As a result of this, Jupiter has practically no seasons, and the orbits of his four chief satellites, which lie nearly in the plane of his equator, generally appear to us as nearly straight lines

found by means of a celestial globe and an almanac or ephemeris, and the times of his rising, southing or setting can be learnt from the same sources

This planet is not usually as well defined as Mars and Saturn in a telescope, and particularly with high powers In 1905 the writer tried some experiments with different powers on reflecting telescopes of 12 6-inch (Calver) and 10-inch (With) mirrors and focal lengths 9 feet 6 inches and 6 feet 6 inches

His results for the 12 6-inch were as follows —

Powers	
205 and 225	Superb definition—small images
312 and 315	Very effective Best powers for general planetary work
404 and 440	Little advantage over 315 except on very good nights, when they are better for detail
572	No gain, in fact 500 seems to be the utmost limit
710 and 713	Pretty sharp image and many details satisfactorily seen, but vibration troublesome and images faint and not satisfactory



JUPITER

This gives an idea of Jupiter and his four chief satellites as they appear in the field of view of a powerful telescope.

912	Single lens—good Better results than with ordinary eye-pieces of about 700
1210	Indistinct and faint, details blurred Not nearly so good as one-third the magnification
1540	Single lens Pretty distinct at centre of field Many spots well seen, but the rapid motion and vibration spoil view and render effective working impossible

When high powers are necessary the *single lens* is a great advantage though the field is very small W Herschel, Dawes and other able observers realised its value and acted upon it

Observers of Jupiter should not overpress magnifying power, but accustom themselves to one eye-piece or two at most On a really good night with a ten-inch glass a power of 375 might be best, and on normal nights about 315 But every observer may discover with a little experience the powers which are the most suitable for the observational work in which he is engaged Low powers

mean sharp definition, a bright object, little vibration, but a small image, while high powers mean inferior definition, a fainter object, greater vibration, but an expansive image

Jupiter's details come out splendidly near the time of sunrise or in daylight before sunset until darkness makes the picture brilliant, for the full lustre of the planet may be apt, in a large glass, to overcome delicate features

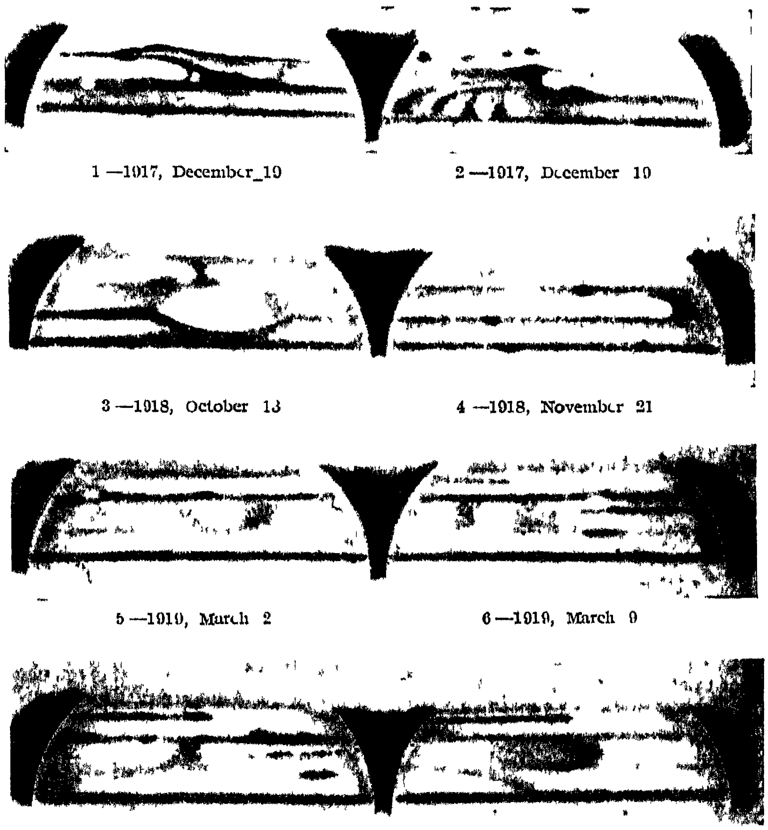
The telescopic definition of Jupiter varies greatly according to the altitude of the planet From 487 nights of observation (ten-inch reflector) at Bristol the following percentages were obtained —

Nights	*Very good*	*Good*	*Fair*	*Bad*	*Very bad*	
Jupiter south of equator	7 0	14 1	15 5	33 8	29 6	= 100 0
Jupiter north of equator	19 8	29 1	25 6	18 6	7 0	= 100 1

The motion of Jupiter along the zodiac carries him alternately from about 23° N of the equator to 23° S of it From the latitude of Greenwich the extreme altitudes of the planet at southing vary between $15\frac{1}{2}°$ and $61\frac{1}{2}°$

Some of the objects observed circulating in Jupiter's atmosphere are very durable, others are only temporary Chief among them all is the "Great Red Spot," which created quite a sensation among planetary observers in 1878 and later years It had, however, been a well-observed feature long before that year, for Dawes figured it in November, 1857, while a few years later it was independently recognised by many observers, including Jacob, Baxendell, Huggins, Long and others The spot exhibited an intense red colouring, and its symmetrical oval shape formed a striking and durable feature of its appearance Since 1857 the spot has passed through many vicissitudes and gradations of tint, assuming a deep, brick-red colour for some years about 1878–1881, and becoming a wonderfully conspicuous and almost startling object on the planet's surface

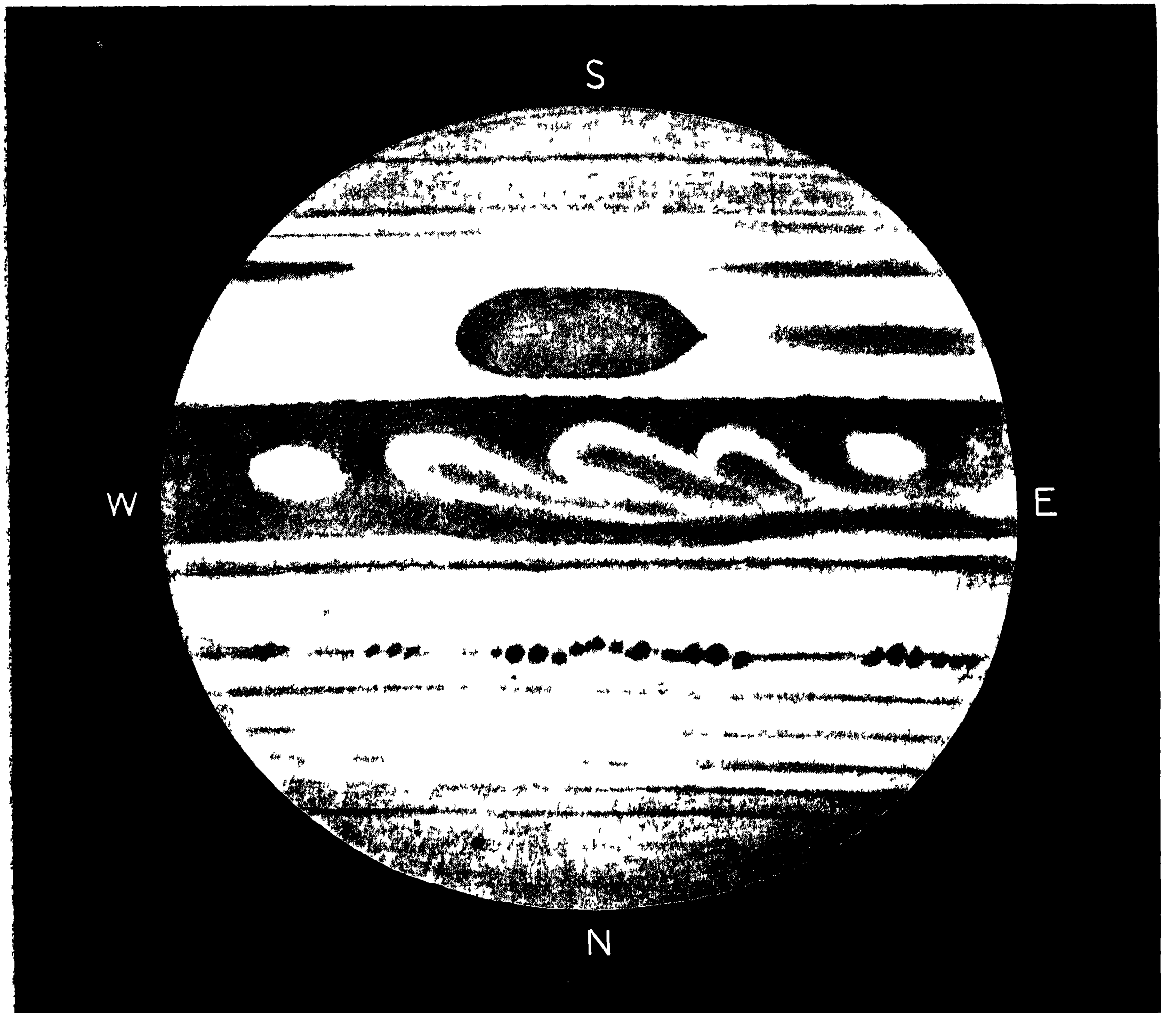
Every telescopic observer turned his instrument on Jupiter and obtained for himself a view of the "Great Red Spot" It quite merited its description as the most remarkable planetary marking that had ever been seen Was it the same spot that had



From M N, R A S] [*T E R Phillips*

THE SOUTH TROPICAL REGION OF JUPITER

These drawings illustrate the remarkable change which occurred in this region a few years ago The two top drawings show the South Equatorial Belt in its usual strength and with the now famous South Tropical Disturbance between this belt and the South Temperate Belt Drawing 3 shows, in addition, the "hollow" in which the great "Red Spot" is situated, together with some indication of the spot itself In drawing 4 the South Tropical Disturbance is advancing on the visible disc on the right-hand side In drawings 5 to 8 we note the fading of the southern portion of the South Equatorial Belt and the South Tropical Disturbance, but the Red Spot remained visible even when its well known hollow disappeared It is seen near the centre in drawings 5 and 8 The white oval spot on the South Equatorial Belt near the left-hand side in drawing 1 and the round black spot are satellite I and its shadow



Drawing by [*W F Denning*

JUPITER, 1880, NOVEMBER 29, AT 7h 35m G M T

The famous Red Spot is shown as a dark, approximately elliptical marking, pointed on its right-hand side The hollow did not exist at this date, the effect being somewhat similar to that observed near the end of 1919 (see drawing on page 349) There is a very remarkable series of minute dark spots on the North Temperate Belt

aroused the enthusiasm of the ancient observers, Hooke, Cassini and others, in 1664 and later years, and which disappeared and reappeared several times ? It is suggestive of identity that it was in the same latitude of Jupiter and had nearly the same rotation period

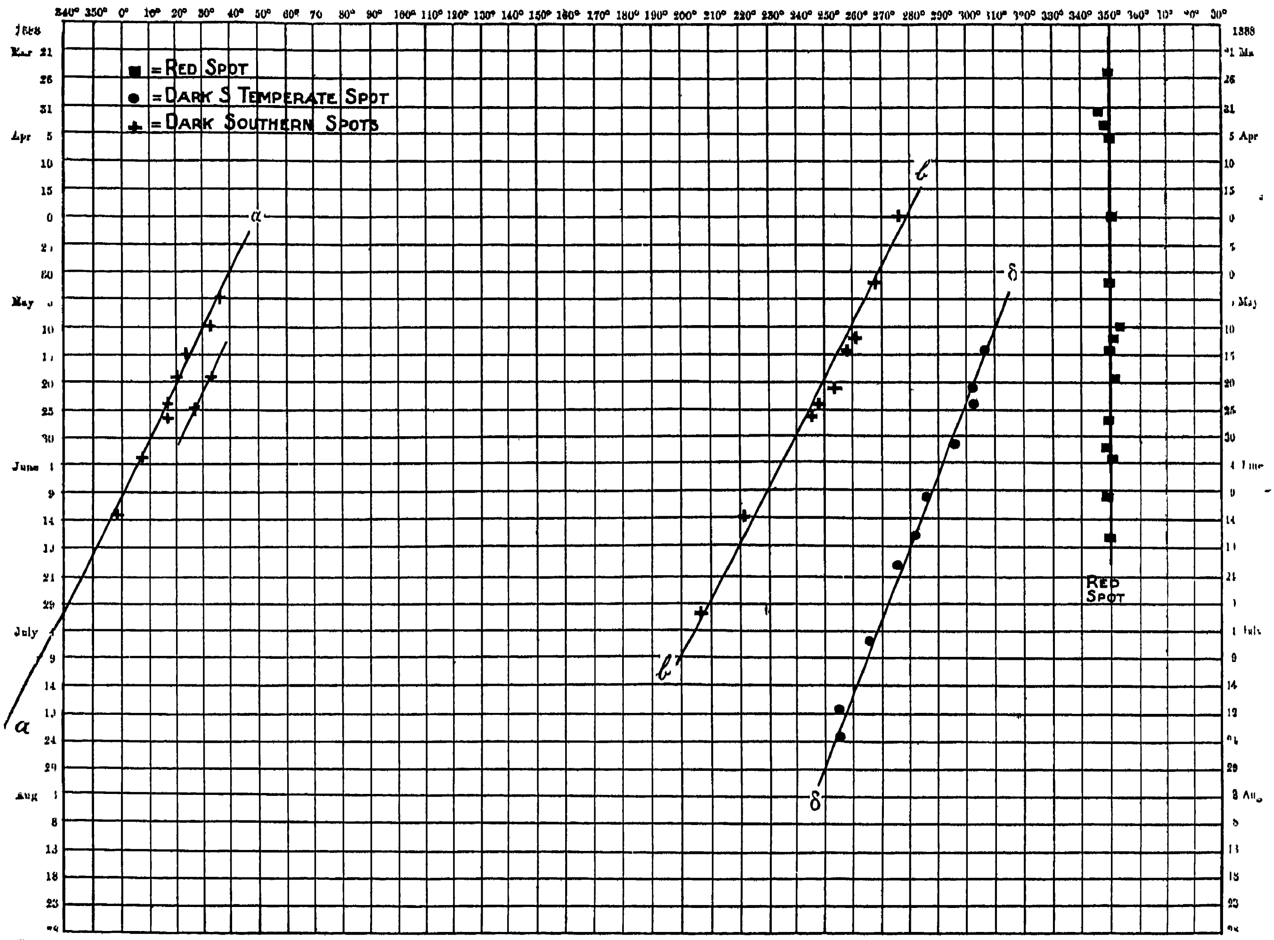
The present spot has usually been situated in a curious hollow or basin in the south side of the southern equatorial belt, and the hollow has been in almost continuous evidence since September 1831 The average rotation period of this object has been 9 hours 55 minutes 36 8 seconds, and about 81,000 rotations have been performed in the nearly ninety-two years' interval to 1923

Hooke was the undisputed discoverer of the great spot on Jupiter in 1664 Cassini followed up observations of this remarkable object, and his name has been so closely identified with it that he has been thought to have first recognised it Priority certainly belonged to Hooke, but he did not pursue the marking and investigate the rotation period to the same extent as Cassini

Hooke's spot of 1664 may well have been closely connected if not absolutely identical with the modern Great Red Spot There are analogies of position and motion which significantly associate the pair of objects and pointedly suggest that they were the same At any rate we may hardly avoid

the inference that they were the outcome of similar phenomena. The red spot of to-day, having survived sixty-six years amid all the vicissitudes of a very active atmosphere, may well have maintained itself during the 259 years which have elapsed since the night of May 19, 1664, when Hooke obtained the first glimpse of it. The marking is now only a relic or shade of its former self, but it may acquire its old-time prominence by a reinvigorating process akin to that which acted upon it in the Seventeenth Century, when it apparently disappeared and reappeared at intervals. Its feeble aspect of late years would have rendered it practically invisible in the old telescopes. Had Cassini possessed more powerful means he might possibly have been able to keep the spot continuously under observation, but his instruments, though the best available at his time, were of limited capacity. Moreover, students of Jupiter were very few and all the circumstances, in fact, tend to prove that a marking, unless of fairly conspicuous kind, could easily have evaded the few eyes and telescopes which were turned critically on to the planet in Cassini's day.

The fact has already been stated that the markings on Jupiter assume the form of approximately parallel belts and zones. New belts appear to be caused by upheavals or ejections from the actual surface, and old belts may be maintained by the same means. New belts were formed under the eyes of observers in the years 1861–2 and 1880–1 in sixty-two days and ninety-one days respectively. In these cases the disturbances affected nearly the same latitude, viz., fifteen to twenty-five degrees



From Zenographical Fragments] [*By A. S. Williams*

OBSERVATIONS OF MARKINGS ON JUPITER

The chart illustrates the determination of rotation periods. Observed longitudes are plotted against the corresponding dates, and lines drawn as evenly as possible through the observations. The slope of a line indicates the drift of an object relatively to the zero meridian, and from this the rotation period can be deduced.

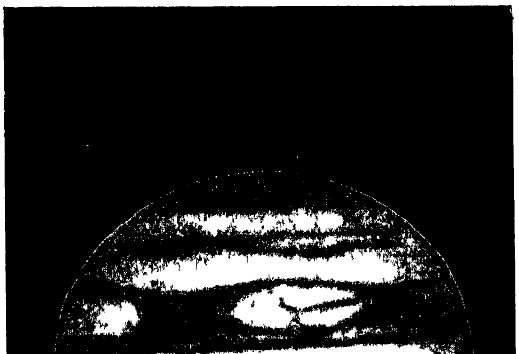
north This region seems liable to special activity at certain periods, and the developments provide very interesting and singular facts which may help us in forming correct views as to the phenomena of the planet's surface

It has been thought that some of the changes on Jupiter may exhibit regular times of recurrence corresponding approximately with the planet's revolution period, but this idea has not been thoroughly proved except in the case of the colouring of the equatorial belts, which Stanley Williams has shown to be repeated at intervals of 11 8 years There is evidence of other variations which are not substantiated on ample proof The fluctuations in the rate of motion of the Great Red Spot on Jupiter have been considerable and apparently induced by the quicker motion of other markings situated in the same

Drawn by] [*J E Keeler*

JUPITER, 1890, OCTOBER 3

This picture of Jupiter, drawn by the late Professor Keeler with the thirty six inch refractor at the Lick Observatory, gives a good idea of the appearance of the Red Spot a few years after its period of maximum prominence The central portions of the spot were the first to fade, leaving a dusky outline at the rim



From "Knowledge"] [*By Latimer J Wilson*

JUPITER, SHOWING THE POSITION OF THE RED SPOT (WHITE OVAL), 1913, MAY 24, AT 8h. 42m G M T

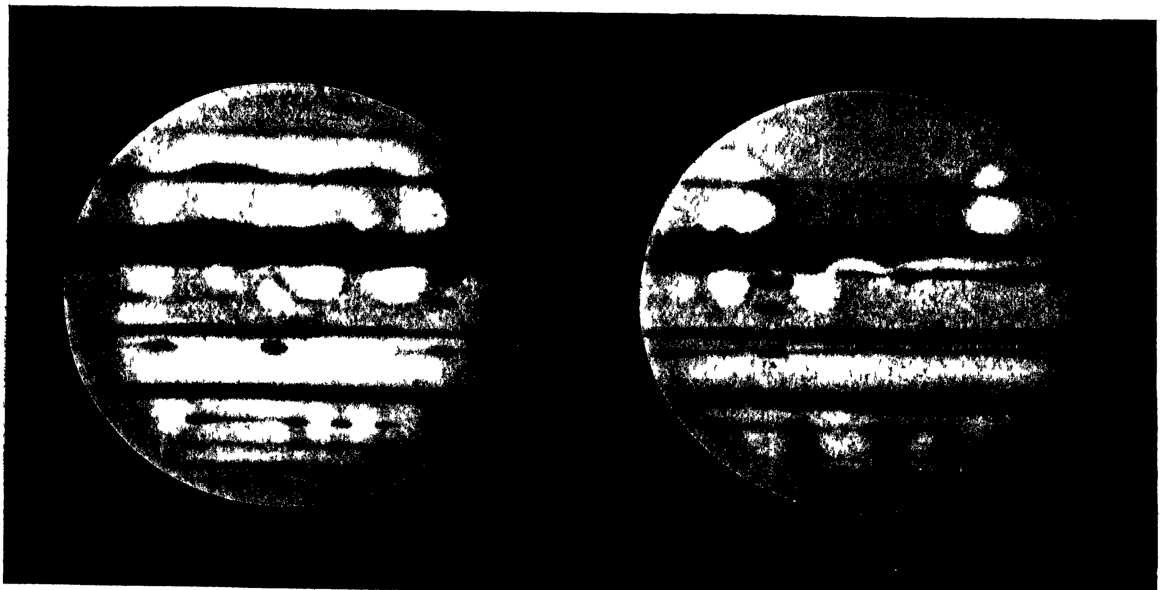
This drawing shows on the left the preceding end of the South Tropical Disturbance Near the centre is the Red Spot Hollow, with some curious streaks across the place of the Red Spot.

south tropical region of the surface The latter have accelerated the motion of the red spot as they have overtaken it and occasioned a distinct shortening in the rotation period of that object The minimum appears to have been reached in 1831, 1877 and 1918, when the values nearly agreed at 9 hours 55 minutes 33 5 seconds, which corresponds to intervals of forty-six and forty-one years and may possibly indicate a cycle of about forty-four years

In 1859 and 1900 the maximum was 9 hours 55 minutes 38 3 seconds and 9 hours 55 minutes 41 6 seconds, the interval being forty-one years

The modern study of Jupiter has differed in important respects from that pursued more than half a century ago Formerly observers viewed the planet irregularly, occasionally made drawings of the features seen, and described any notable details, but they did not follow the work with frequent repetition and the utmost accuracy In recent years the planet has been thoroughly watched, and all the more conspicuous markings with many of the minor features carefully studied over as long periods of time as possible For this purpose many thousands of the times of transit of the spots and irregular markings have been taken as they passed the central meridian Thus the objects have been followed over

several years and identified in many cases at successive apparitions Formerly if a curious marking was seen it was neglected after its detection was announced Now its life history is pursued with a thoroughness and persistency which enable us to determine its period of rotation and its duration, and in some cases to judge of its character One marking, above referred to, has been traced during the ninety-two years which have elapsed since it was first seen by Schwabe in September 1831 Another has been kept under review during the sixty-six years since November 1857, when Dawes made a drawing of the planet These objects are respectively the " Hollow in the Great Southern Belt " and the " Oval Red Spot " in south latitude about twenty degrees, and they remain both visible to-day Another marking, called the " South Tropical Disturbance," showing great changes of motion, extent and shape, has been seen since Molesworth first figured it in February 1901 Certain of the features are of extremely durable character, and must represent something very different from the ever changing and evanescent clouds floating about in our own atmosphere The physical condition of Jupiter's surface must, in fact, be very dissimilar to that of our own sphere



Drawings by] [*T E R Phillips*

JUPITER, 1903, AUGUST 12, AT 13h 40m AND 15h 35m G M T

These two drawings are given for the purpose of illustrating the rapid rotation of the planet They were made on the same night at an interval of approximately two hours It will be seen that the objects near the right hand side of the earlier drawing have been carried across the centre towards the left hand side in the later one The motion is so rapid that a watch of but three or four minutes is amply sufficient to show the turning movement, or rotation, of the planet if the instrument and conditions be good and the observer experienced in such work

and of the envelope surrounding it, in the latter of which great changes and transformations operate from hour to hour

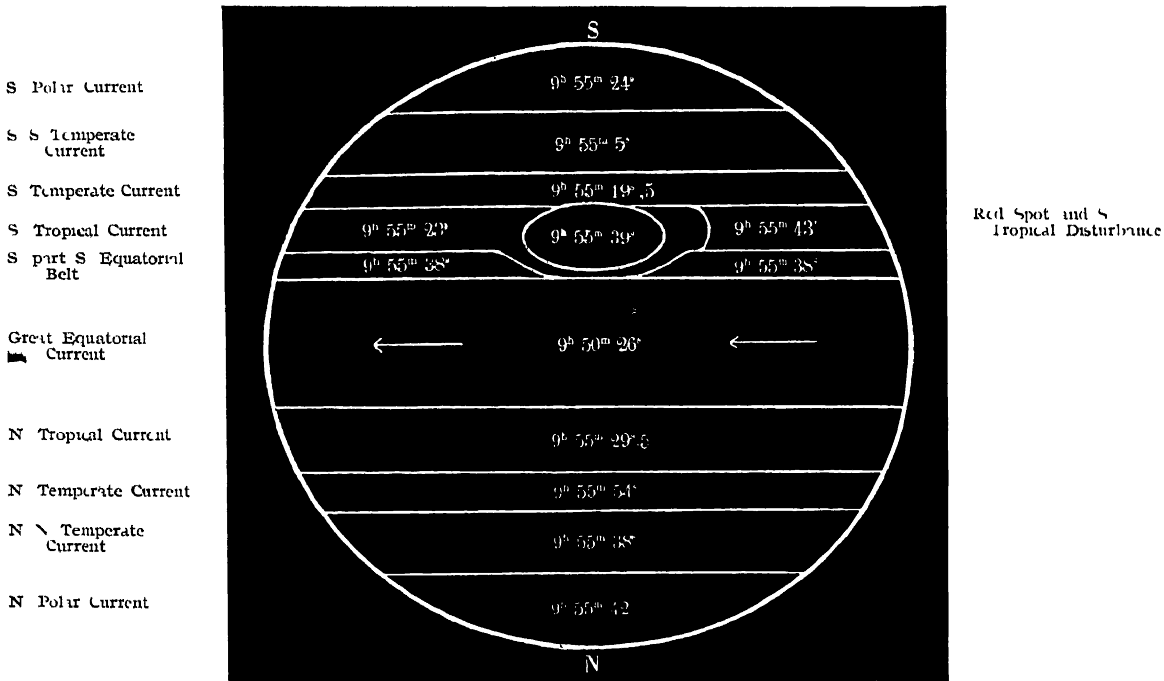
It seems likely that from the surface of the Jovian orb there occur emissions or ejections of gaseous material or vapours which rise to the outer layers of his envelope and may there partially consolidate and assume durable conditions The planet has a motion of rotation very many times swifter than that of the Earth In fact, while Jupiter's equatorial region rotates at the rate of about 470 miles per minute, the Earth's movement is only about seventeen miles per minute The great velocity of Jupiter's globe has the effect not only of causing the polar flattening and equatorial bulge to be very marked, the polar and equatorial diameter being in the ratio of fifteen to sixteen, but also of altering the forms of certain mobile and possibly elastic formations on the planet's disc, which, as above stated, are drifted into the bands or streams of shading which we invariably perceive on the disc and form the belted aspect with which telescopic observers are so familiar

Currents of different velocities influence the movement of the various features, and certain objects in the same latitudes are not moving at the same rates, nor does the same feature maintain an equable rate of speed. Generally the equatorial region contains objects displaying the greatest speed, but this is not invariably the case.

The periods of rotation of the markings differ between 9 hours 48 minutes and 9 hours 56½ minutes.

What the real rotation of the Jovian sphere is we do not know. All the features composing his extensive scenery may be regarded as floating objects in an atmospheric ocean, influenced by a great diversity of currents running in directions parallel approximately at least with the planet's equator.

Thus the study of this orb is justly considered to be of profound interest, and we are not only attracted to the planet by the splendour of his luminous effect in the heavens, but from the fact



From "Scientia." [*T. E. R. Phillips*

THE ROTATION OF JUPITER

As explained in the article, the outer envelope of Jupiter which we see does not rotate like a solid globe, but, as is the case with the Sun, the time required for a rotation depends on the latitude of the object observed. There are quite a number of separate "surface currents," as they are called, moving at different speeds, and these currents are surprisingly sharply bounded. They are indicated in the diagram, together with the adopted values of their mean rotation periods. It is to be noted that the periods of the surface currents show variations within certain limits from year to year, and the figures on the diagram are adopted mean values only. The ellipse in the Southern Hemisphere indicates the "Red Spot."

that his surface presents a scene of great variety and activity. He forms an object which can never be considered to present the monotony of sameness. There may be something always akin in his general aspect, but in detail he may exhibit striking activities from night to night. New objects are frequently forming and old ones either disappear or exhibit changes of shape, motion or colour.

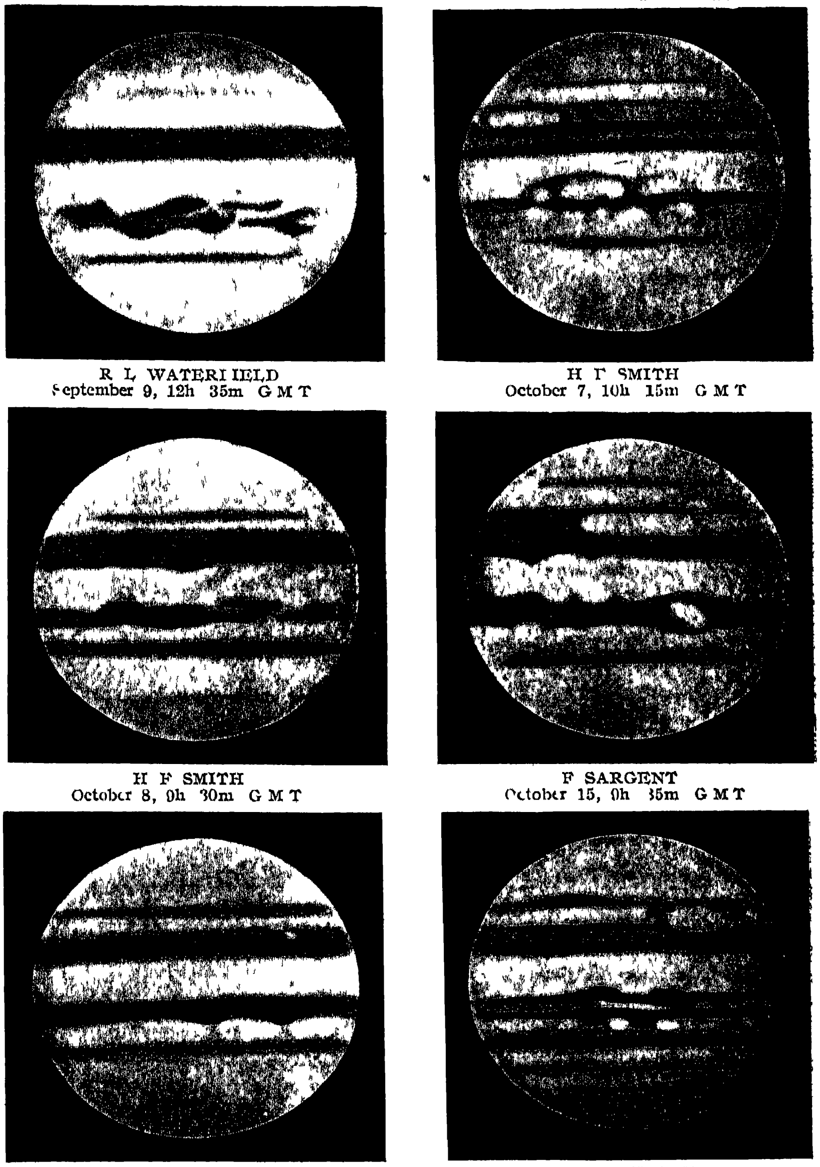
Jupiter presents some analogies with the Sun in regard to the mobile character of his envelope. The rotation period of the solar orb is different according to the latitude, and there are evidences of great activity usually present. Some years ago it was suspected that certain visible phenomena on Jupiter exhibited a periodical recurrence corresponding with his time of revolution (11.8 years) and not differing greatly from the intervals separating sun-spot maxima. The colour changes on the Jovian orb already referred to appear to be pretty consistent with the period named, though in some other respects irregularities occur opposing the idea of cyclical disturbances. No doubt the planet

gives strong indications that similar phenomena producing spots, belts and irregular features are repeated from time to time, but not always with consistency as regards the periods

In another respect there is an analogy between Jupiter and the Sun, for both objects show regions of greatest activity at certain distances north and south of the equator The solar spots appear in greatest frequency in belts or zones from latitude ten degrees to twenty degrees in the north and south tropical regions, and the two principal belts on Jupiter, in which numerous spots and irregularities occur, are usually placed in nearly similar latitudes to those mentioned

With regard to the physical condition of the planet and the relative heights of the various markings a number of writers have expressed their views, and they are by no means consonant, but rather appear, in some cases at least, to be contradictory

With reference to the Great Red Spot, Phillips considers that there is strong evidence favouring the idea that it is " a vortex—analogous to a cyclone on the Earth, though its prolonged existence shows that it must be of great strength and probably deep seated below the planet's visible surface This theory is doubtless not free from objections, but it may fairly be said that it fits the facts better than any other " He points out that we might expect " vortices to occur along the lines of contact between viscous currents possessing diverse velocities, and if many Jovian spots are of this charcter we then have another analogy between Jupiter and the Sun "



R L WATERFIELD
September 9, 12h 35m G M T

H F SMITH
October 7, 10h 15m G M T

H F SMITH
October 8, 9h 30m G M T

F SARGENT
October 15, 9h 35m G M T

J H BRIDGER
October 20, 11h. 5m. G M.T

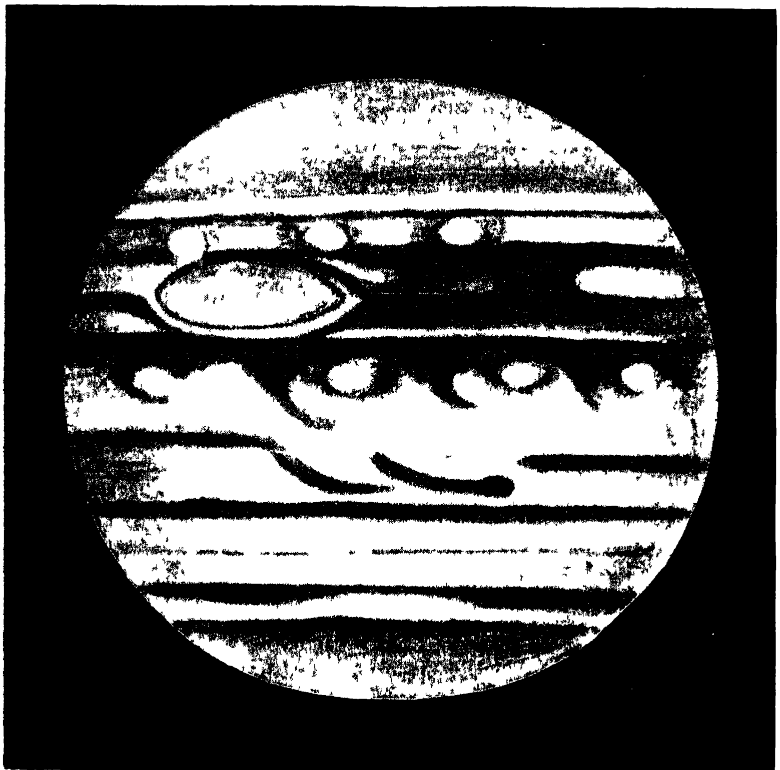
M A AINSLIE
November 7, 7h 14m. G M.T

By permission of] [*The British Astronomical Association*

JUPITER IN 1916

These drawings were made by members of the Jupiter Section of the British Astronomica Association It will be noted that in all the North Equatorial Belt is the most disturbed region of the disc, great irregularities being shown at its edges In Bridger's drawing satellite I and its shadow are shown close together on the South Equatorial Belt The shadow of II is seen on Ainslie's drawing

The dusky belts may possibly be comparatively clear tracts and situated at a lower level than the bright zones, which may represent cloudy regions of strongly reflective vapours, such as our cumulus Lau interpreted the bright spots as centres of eruption similar to the bright markings



Drawing by] *W F Denning*

JUPITER, 1906, APRIL 15, AT 5h 30m GMT

Towards the left in this drawing is seen the old Red Spot as a well defined ellipse lying in its hollow on the south side of the South Equatorial Belt To the right of this we see the South Tropical Disturbance This object was first seen by the late Major Molesworth, in Ceylon, on February 28, 1901, as a small round projection, at the south edge of the South Equatorial Belt It quickly showed striking developments, spreading across the South Tropical Zone to the South Temperate Belt, and at the same time becoming greatly extended in longitude At times it has exceeded 180° in length A white spot has usually been seen at the preceding and following ends

which terrestrial volcanoes may occasion when very active by the ejection of smoke, steam and other highly reflective vapours The fact is, however, that the results of speculation with regard to the condition of Jupiter and the causes and character of his visible phenomena are hardly likely to represent the true state of things Our own Earth and surroundings must necessarily influence us in judgment and may lead us to see analogies where none exist more than distant physical resemblances In fact, other planetary worlds may be so utterly different from our own as to afford novelties such as we can neither conceive nor understand, for the circumstances affecting, say, Mercury or Jupiter are vastly different from those which influence and direct terrestrial phenomena The changing aspects blended with stable features, all exhibiting a singular variety of motion and some of them of enormous dimensions, can find no counterpart in the aerial sea surrounding our own globe It is the recognition and pursuit of the many variations presented that make the study of Jovian features so highly interesting

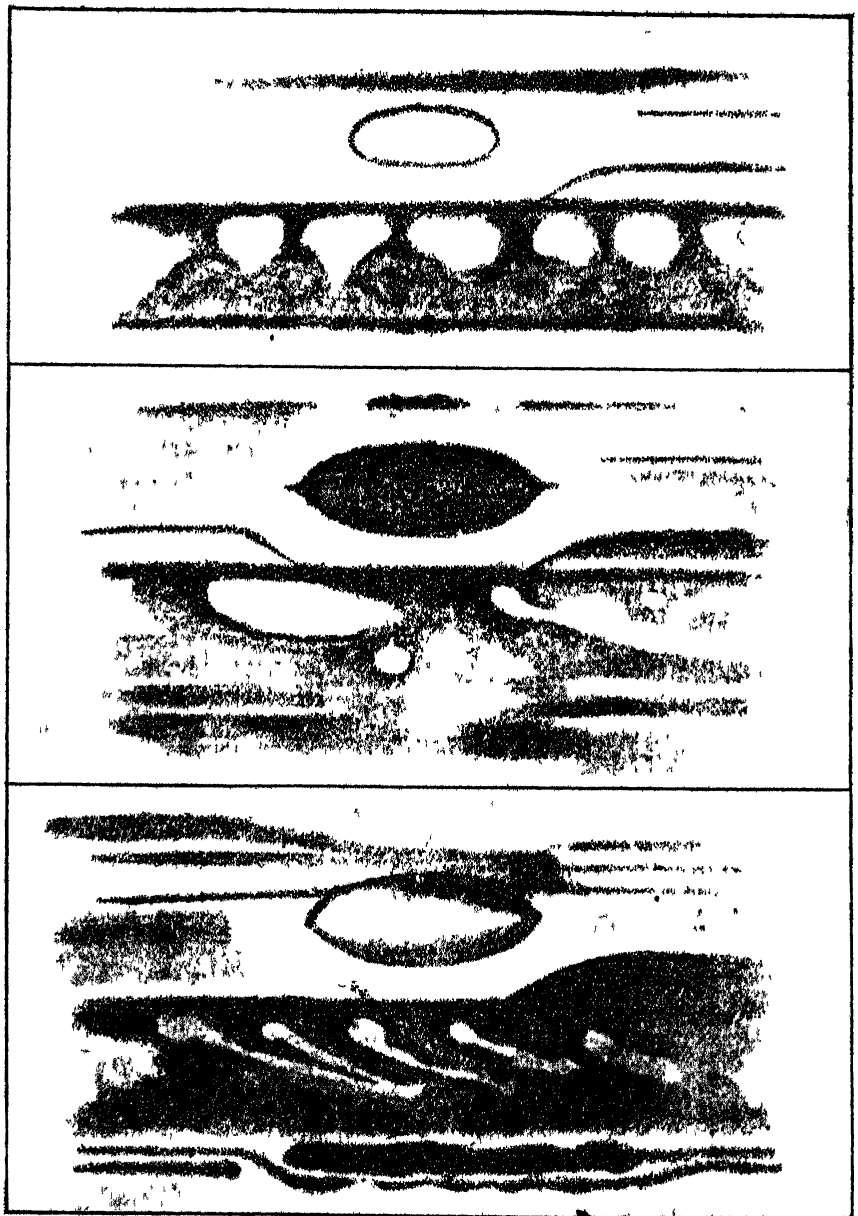
Jupiter's currents are in a longitudinal direction and differences have been detected among them to the extent of about eight and a half minutes for one rotation The motions show not only relative differences according to the latitude, but that the same objects are liable to variations of speed Thus the Great Red Spot, in about south longitude twenty degrees, has varied between 9 hours 55 minutes 33 seconds and 9 hours 55 minutes 42 seconds, and the equatorial spots between 9 hours 50 minutes 6 seconds and 9 hours 55 minutes 35 seconds during the past forty years, and occasionally these limits have been exceeded in the behaviour of individual spots But, though there have been notable exceptions, the same latitudes are generally controlled by nearly similar rates of movement, so that, when the position of a marking is known, we may pretty correctly estimate what its rotation period will be On one occasion, however, in 1880 there was an outbreak of spots showing a period of only 9 hours 48 minutes, though the same latitude (about twenty-five degrees north) usually gave 9 hours 55 minutes 30 seconds!

Observers who habitually watch and critically record the surface markings of this planet note some singular developments Owing to their swifter movement the equatorial spots completed a revolution around Jupiter relatively to the Red Spot in forty-four and a half days in 1880, and the

two objects came into conjunction at this interval In 1901 the dark south tropical disturbance occasioned spots in nearly the same latitude as the Red Spot The former rotated in about twenty seconds less time than the latter, and successive conjunctions happened in rather less than two years This period is now lengthened to about six years owing to changes of motion in the objects, and there is a difference of only six and a half seconds in the rotation periods

There are a great number of variations occurring in the outer envelope of Jupiter, and these are ever introducing features of peculiar interest Not only in rotation and proper motions, but in shape and size the spots and markings are ever displaying variety The south tropical marking, mentioned above, has changed in length from about 25 degrees to 180 degrees, which is equivalent to something like 100,000 miles of Jovian longitude! So it is evident that alterations of this kind are on a gigantic scale and they are conspicuously obvious in our telescopes though situated at a mean distance of 480 millions of miles During the last twenty-three years the south tropical spot or disturbance has occasioned great irregularities in the motion of the Red Spot, a fact foreseen and first announced by E M Antoniadi

When we realise how much the telescope illumines our understanding as to many of the hidden secrets and wonders of Nature we cannot but appreciate the remarkable powers of this instrument



Drawings by] [*J Gledhill and W F Denning*

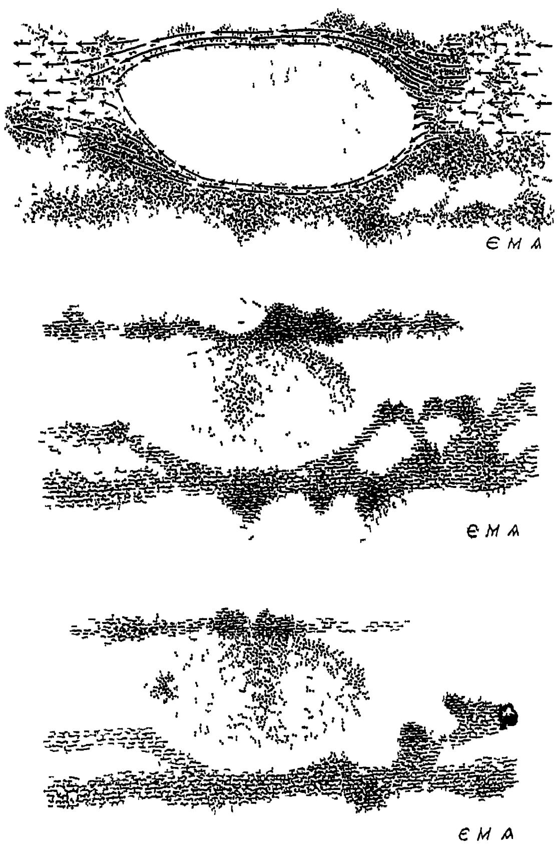
THE RED SPOT

Three different aspects of the Red Spot are here shown The top one is a drawing by Gledhill, in 1870, January 23, 8h 20m, on which the object appears as a simple elliptical ring The middle drawing, by Denning, was made about four years after the object became so conspicuous, and it shows pointed ends such as have been observed at various times They are extremely difficult to explain In the lowest drawing, by Denning, in 1886, October 11, 11h 54m, the spot is shown greatly faded, and the pointed ends have become mere dark dots

To natural vision only Jupiter shines simply as a star in our skies, but the telescope at once reveals it as a large globe full of activity and rich in detail, while a numerous retinue of nine attendant moons is found to revolve around him

Students of Jupiter at one time experienced a difficulty in referring to certain belts, localities or latitudes on the planet, and devised an expressive nomenclature to enable them to define and describe positions in latitude

The chief belts and zones are generally somewhat similar, and suggested to various observers an obvious means of reference as illustrated in the diagram on page 334 Thus if a spot was seen in the southernmost dark belt it would be said to be on the S S temperate belt, and so on This arrangement usually meets requirements, but the belts are changeable and not always symmetrically placed, though there are nearly always two great belts bounding the equatorial zone Occasionally there are a large number of belts lying in parallel lines (like stratus clouds) in one hemisphere



Drawings by] [*E M Antoniadi*

THE RED SPOT

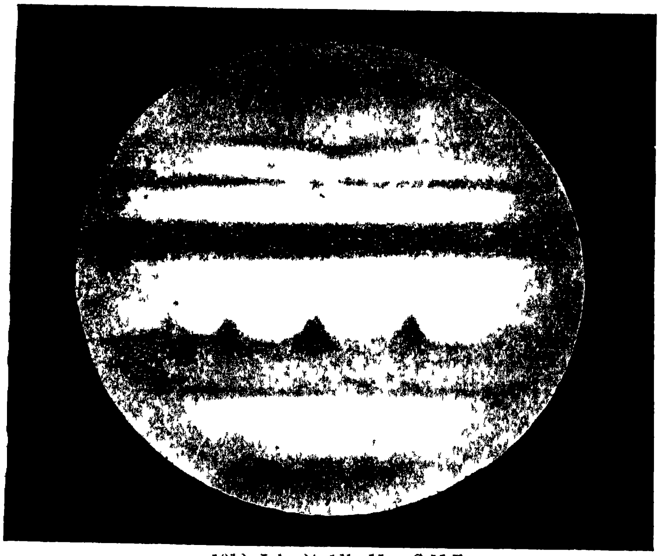
The South Tropical Disturbance is situated in the same latitude as the Red Spot, and, moving more quickly, periodically overtakes it At such times it is invariably found that the motion of the Red Spot becomes accelerated, and the upper drawing illustrates M Antoniadi's explanation that the dark material of the Disturbance pushes on or carries forward the Red Spot as it flows round or below that famous marking The two other drawings, made with the Meudon thirty three inch refractor, on 1911, May 22, at 10h 47m G M T, and on 1911, July 7, at 8h 36m G M T respectively, show some interesting details The Spot itself is pointed at its preceding (left-hand) end, and near the latter a curious dark, curved marking is shown in the bottom drawing Note the changes in the region of the following (right hand) "shoulder" of the hollow

Mr A Stanley Williams, the Rev T E R Phillips and others have determined the general rate of rotation for various latitudes, and there is fair consistency, if not absolute agreement, in their independent deductions Ephemerides are published every year in the *Nautical Almanac* containing data of great value to students of the planet, and in a still more convenient form in *A Handbook for Observers*, published by the British Astronomical Association By the help of these an observer may find, *e g*, when to look for the Great Red Spot and may reduce his own observations Two rotation periods are used, viz, 9 hours 50 minutes 30 004 seconds, and 9 hours 55 minutes 40 632 seconds, and with these the observed motions of spots may be readily compared The first of these systems is intended to represent equatorial markings which indicate a rotation performed in about five minutes less time than that of the Red Spot and the second represents approximately the period of features commonly seen outside the equatorial zone

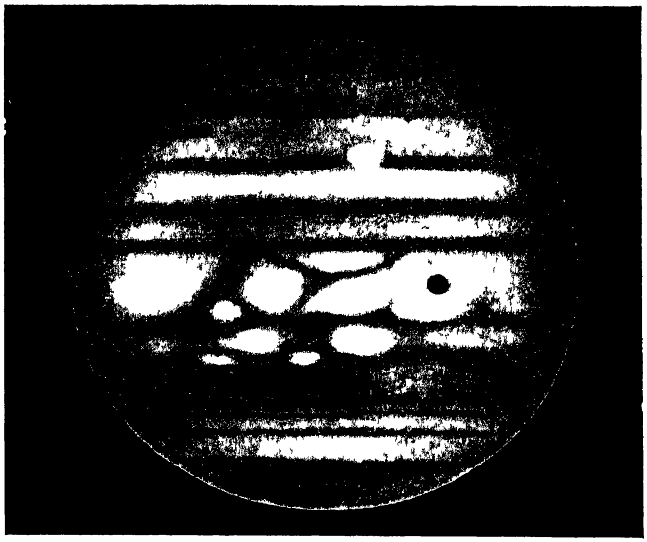
The following table will show the equivalent values of time and degrees of longitude on Jupiter according to the two systems

Minutes of time	System I 9h 50m 30 004s Degrees	System II 9h 55m 40 632s Degrees
0 5	0 305	0 302
1 0	0 610	0 604
5 0	3 048	3 022
10 0	6 097	6 044
50 0	30 483	30 218
100 0	60 967	60 437
200 0	121 934	120 874
300 0	182 900	181 310

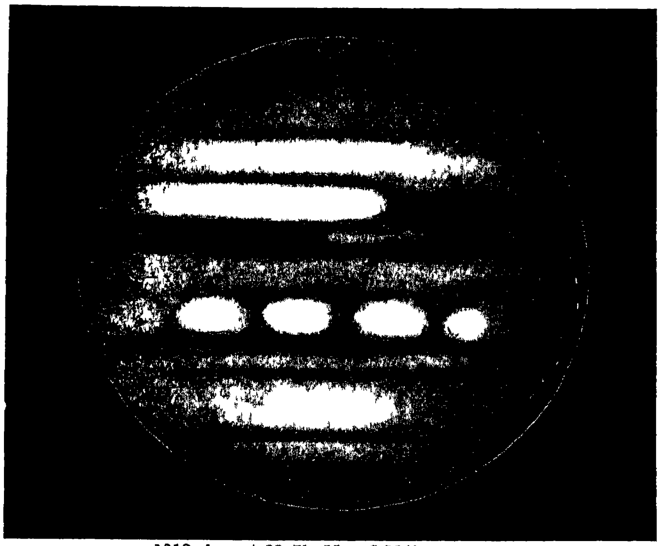
Jupiter is so large that he must necessarily and



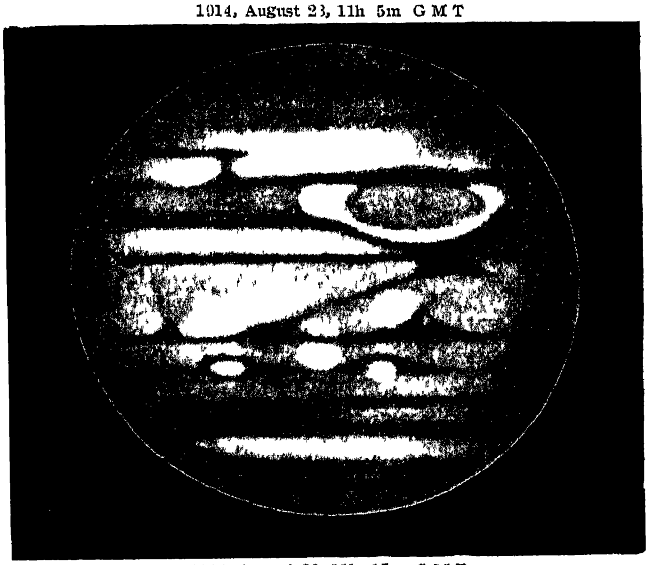
1913, July 24, 11h 15m G M T



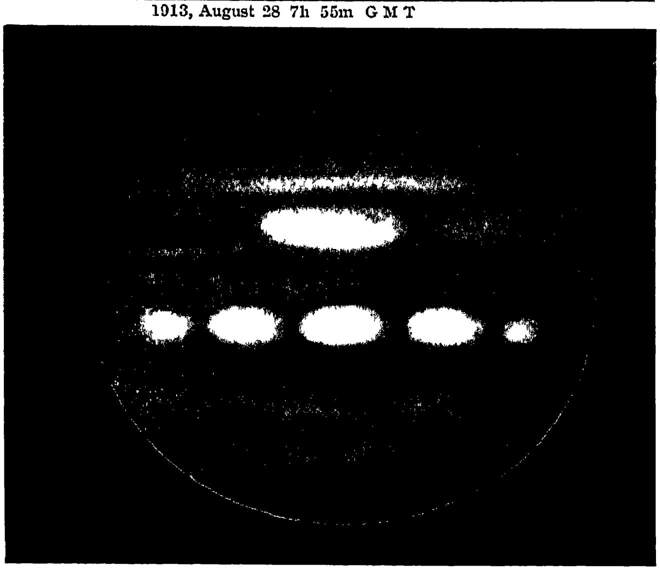
1914, August 23, 11h 5m G M T



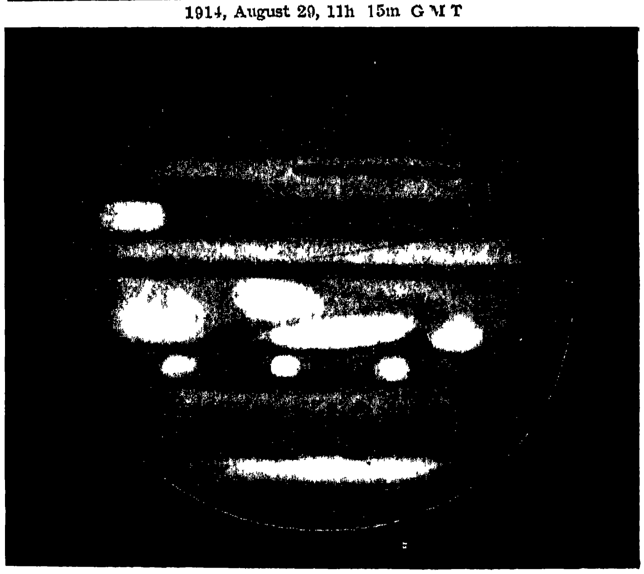
1913, August 28 7h 55m G M T



1914, August 29, 11h 15m G M T



1913, September 12, 7h 30m G M T



1914, August 31, 10h 30m G M T

From "Knowledge"] [*T E R Phillips*

SIX DRAWINGS OF JUPITER

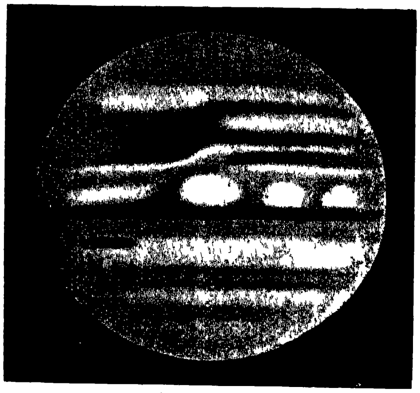
The three drawings on the left-hand side show the remarkable series of large bright egg-shaped markings in the north part of the Equatorial Zone, bordering the North Equatorial Belt, which appeared in 1913 They showed a much more rapid rate of rotation than had been observed for several years The three drawings on the right show the planet's aspect in 1914 Note the curious link like markings on the two upper ones

obviously influence the movements and stability of many of the lesser orbs Some of the minor planets are affected Comets are occasionally drawn out of their courses, and any of these bodies passing near him will be perturbed in more or less degree according to the conditions He is capable of impressing new paths upon some of them

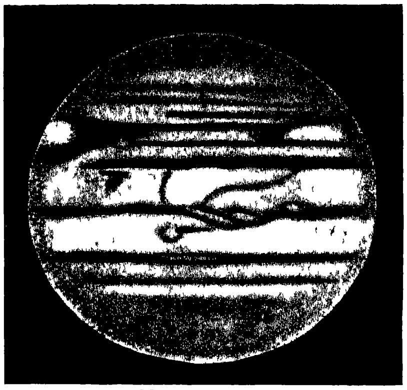
The story of Lexell's comet of 1770 and its changes of orbit when near Jupiter have often been described in textbooks

How the November Leonids were attracted away from the Earth so far at their perihelion in 1899 that they could not produce a grand display is familiar in astronomical history

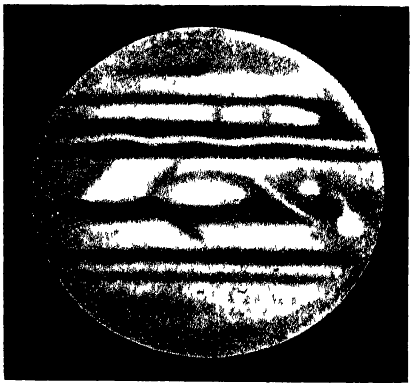
Jupiter is specially responsible for many extensive disturbances which have occurred in the movements and orbits of comets His great powers of attraction seem, indeed, to have enabled him to form an important cometary group or community of his own He appears to have deflected certain comets of long period away from the very eccentric ellipses they formerly traversed to ellipses more nearly approaching circles and requiring short periods of revolution The average of about forty comets is six and a half years Their greatest distance from the Sun



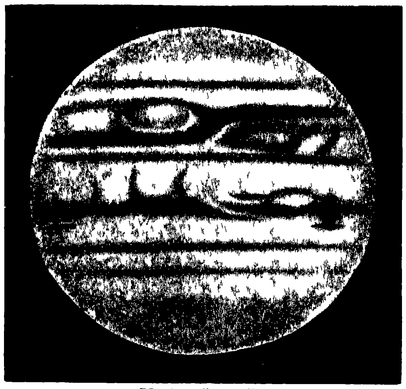
F SARGENT
1 —August 18, 16h 0m G M T



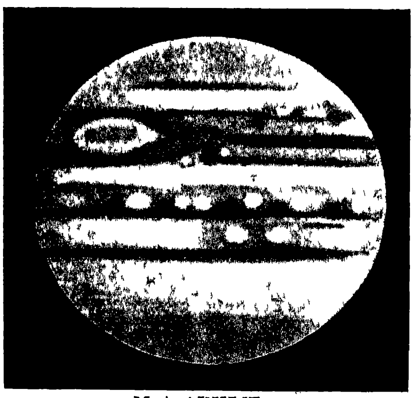
M A AINSLIE
2 —October 27, 12h 25m. G M T



H THOMSON
3 —November 19, 11h. 15m. G M T



M A AINSLIE
4 —November 25, 9h 30m G M T



M A AINSLIE
5 —December 7, 9h. 50m. G M T

H THOMSON
6 —December 14 8h 55m. G M T

By permission of] [*The British Astronomical Association*

JUPITER IN 1917

Another series of drawings by members of the Jupiter Section of the British Astronomical Association The preceding end of the South Tropical Disturbance is seen in Drawings 3 and 6, and the following end in Nos 1 and 2 The Red Spot Hollow is shown near the preceding limb in Nos 2 (going off the disc at preceding limb), 4, 5, and 6 The Red Spot itself is also shown lying in its hollow in the last three of these drawings Dark streaks are shown north of the North Equatorial Belt in Drawings 1, 2, 4, 5, and 6 They were quite a feature of the planet in 1917

Drawing by] [*T E R Phillips*

JUPITER, 1919, NOVEMBER 29, AT 14h G M.T

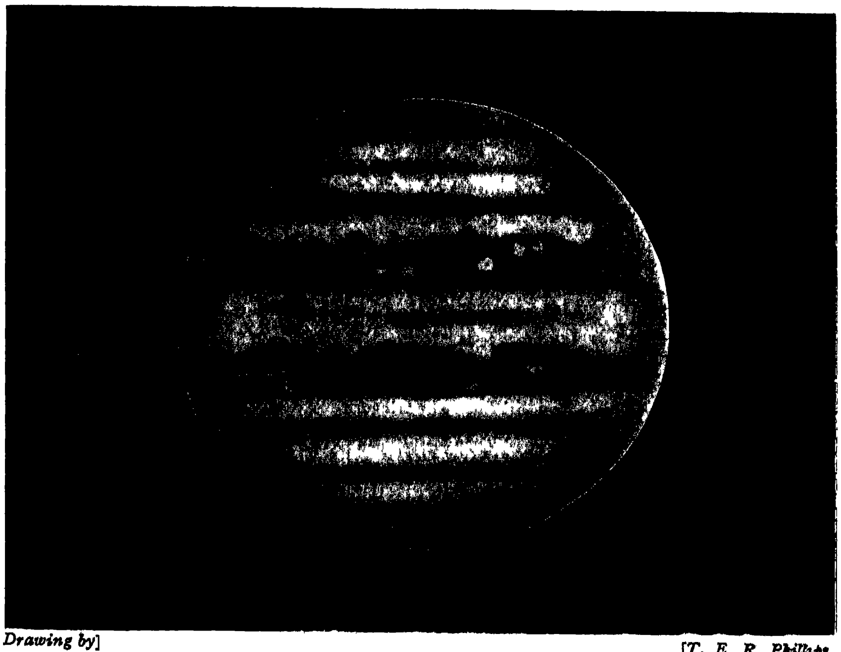
This drawing shows the complete disappearance of the southern portion of the South Equatorial Belt and the Red Spot Hollow The right-hand portion of the peculiar elongated marking in the South Tropical Region is the Red Spot, which became more plainly visible as its surroundings faded away

nearly corresponds with his orbital position, so that he sometimes approaches quite near certain of these bodies, as their orbits are of small inclination The positions and periods of the comets of short period in the Solar System are significant and eminently suggestive that Jupiter was mainly and materially responsible for their present curious distribution

This great orb moving around his orbit through the ages would naturally nearly encounter many comets and meteoric systems, and by oft-repeated action would ultimately draw them into the new orbits which they pursue to-day Many circumstances agree in suggesting this conclusion, and in supporting its actuality, though it is not universally accepted

The Jovian Comets are of little inclination, their aphelion distances agree nearly with that of Jupiter's orbit, and their motions are direct In fact, if we look at a plan of the Solar System which includes the known periodical comets we cannot but receive the decided impression that Jupiter's action has been very largely responsible for the extensive family of those revolving in short periods

Among those whose persevering study of the surface markings of Jupiter

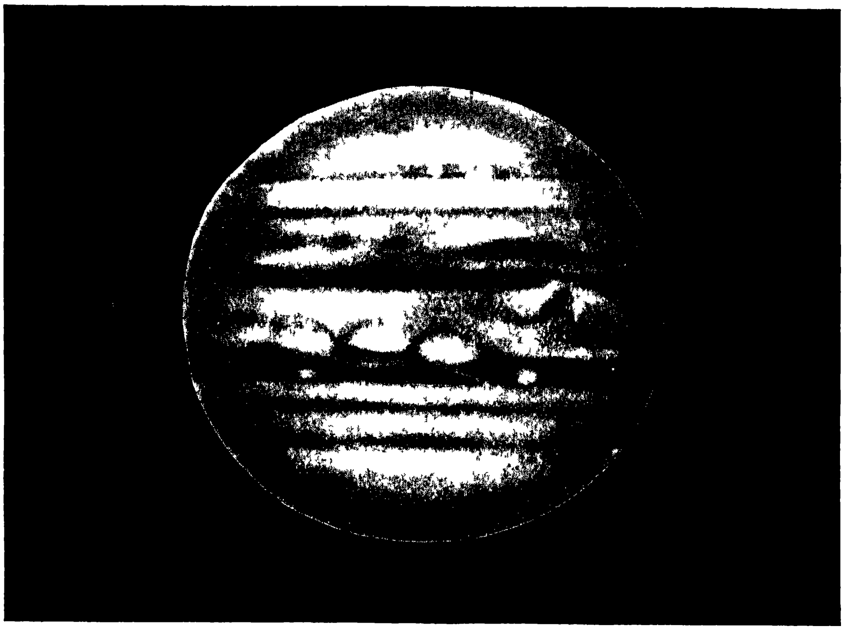


Drawing by] [*T. E R Phillips*

JUPITER, 1920, FEBRUARY 13, AT 12h 40m G M T

In the early part of 1920 we saw the great revival of the South Equatorial Belt, the Red Spot Hollow, and the South Tropical Disturbance The developments about this time were quite startling in their suddenness, and it was difficult to recognise the same features after the lapse of but two or three days only The drawing gives an idea of the number of white and dark spots which marked the restoration of the belt

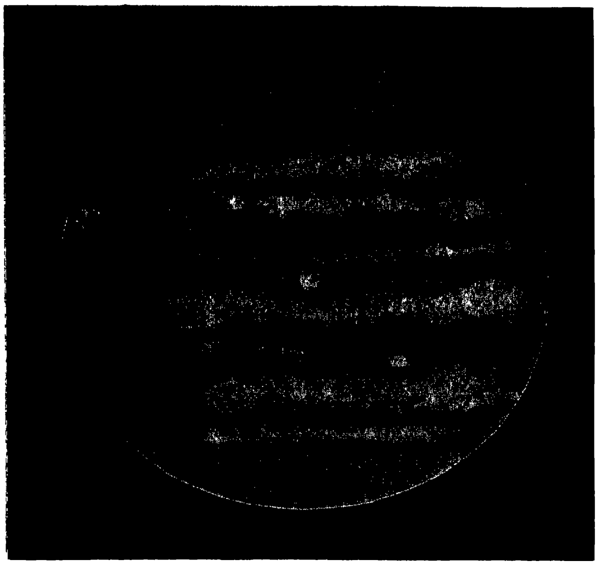
has greatly contributed to our knowledge during the last half century may be mentioned A Stanley Williams, Schmidt, Professor Hough, Dr Terby, Major Molesworth, Gledhill, Rev T E R Phillips, and many others have engaged in the work We are now acquainted with the general aspect of the planet and have a good idea of his visible phenomena as displayed in the markings Molesworth at Ceylon obtained tens of thousands of transits of these abundant features and deduced the rates of rotation for some hundreds of them of different character situated in various latitudes on the disc Phillips has also devoted himself to the study during a long series of years with an ability and devotion only equalled by his success Thus it may safely be said that since the Great Red Spot became so prominent about fifty years ago, we have acquired pretty complete and reliable records of Jovian objects



Drawing by] [*T E R Phillips*

JUPITER, 1922, APRIL 4, AT 11h 15m G M T

In the drawing there is a curious dark marking projecting into the Equatorial Zone from the northern edge of the South Equatorial Belt, and this marking exhibited an abnormally slow rate of motion for its latitude

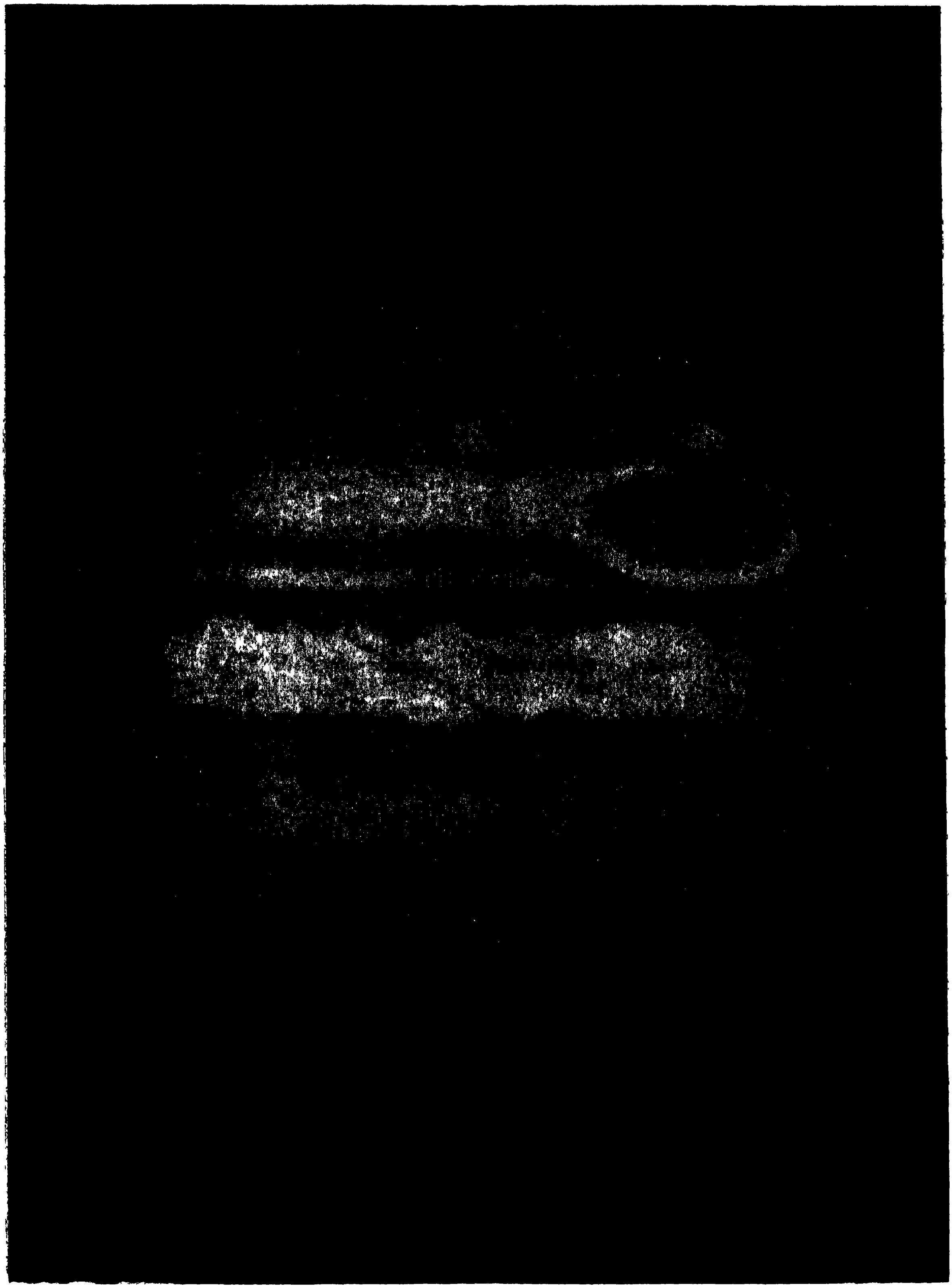


Drawing by] [*T E R Phillips*

JUPITER, 1923, MAY 1, AT 12h 30m G M.T

A portion of the Red Spot Hollow is seen on the left, and extending from this, across the disc, is the South Tropical Disturbance as a series of rather faint irregularities Note the bright rift in the North Equatorial Belt

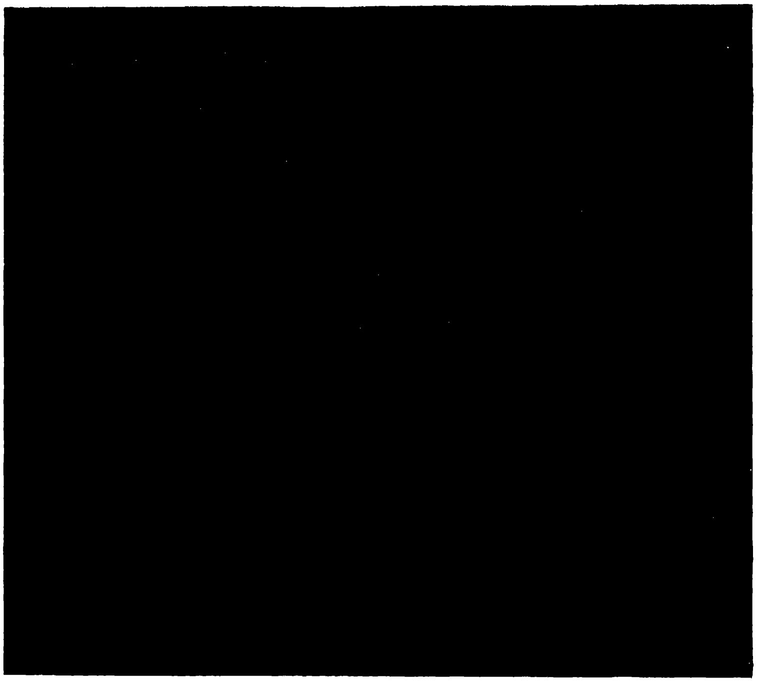
These will be valuable, and especially so at a future time, when combined with further data of similar kind, for the more advanced investigation of Jovian surface phenomena The recurrence of certain spots in particular latitudes may be proved and we may find to what extent similar rates of motion are repeated Cycles of changes may become evident It is only by lengthy and continuous effort at succeeding oppositions that our knowledge can be much enhanced The earlier observers of Jupiter apparently did not recognise the necessity of thoroughness and frequency in watching the very plentiful detail displayed on the disc The work is certainly one of great magnitude, and a man engaged on this planet must expect that all his energies and his whole time will be absorbed in the pursuit He will find it possible to take more than 100 transits of spots during a single night, and that more than 200 different markings may claim his attention during one and the same opposition



Drawing by]　　　　　　　　　　　　　　　　　　　　　　　　*E M Antoniadi*

JUPITER, 1911, MAY 22, AT 10h 7m G M T

This beautiful drawing, by one of the most accurate astronomical draftsmen of our time, was made with the aid of the thirty-two-and-three-quarter inch telescope of the Meudon Observatory, which is the largest refractor in Europe It gives an excellent idea of the general appearance of the planet, as seen in a powerful instrument Like all other planetary drawings, it is purposely executed on a large scale to facilitate reproduction, and it should be viewed from a distance of five or six feet to obtain an idea of the approximate apparent size of the planet as seen in the telescope



Photo] [*Lick Observatory*

JUPITER, 1891, OCTOBER 12

This photograph was taken at a time when the Red Spot was far more conspicuous than it has been in recent years Its redness also caused it to be more prominent photographically than visually

The two planetary objects which are the most diversified and attractive for telescopic study are Mars and Jupiter

Mars apparently displays lineaments which form the material surface of the planet, while Jupiter's visible features are merely atmospheric

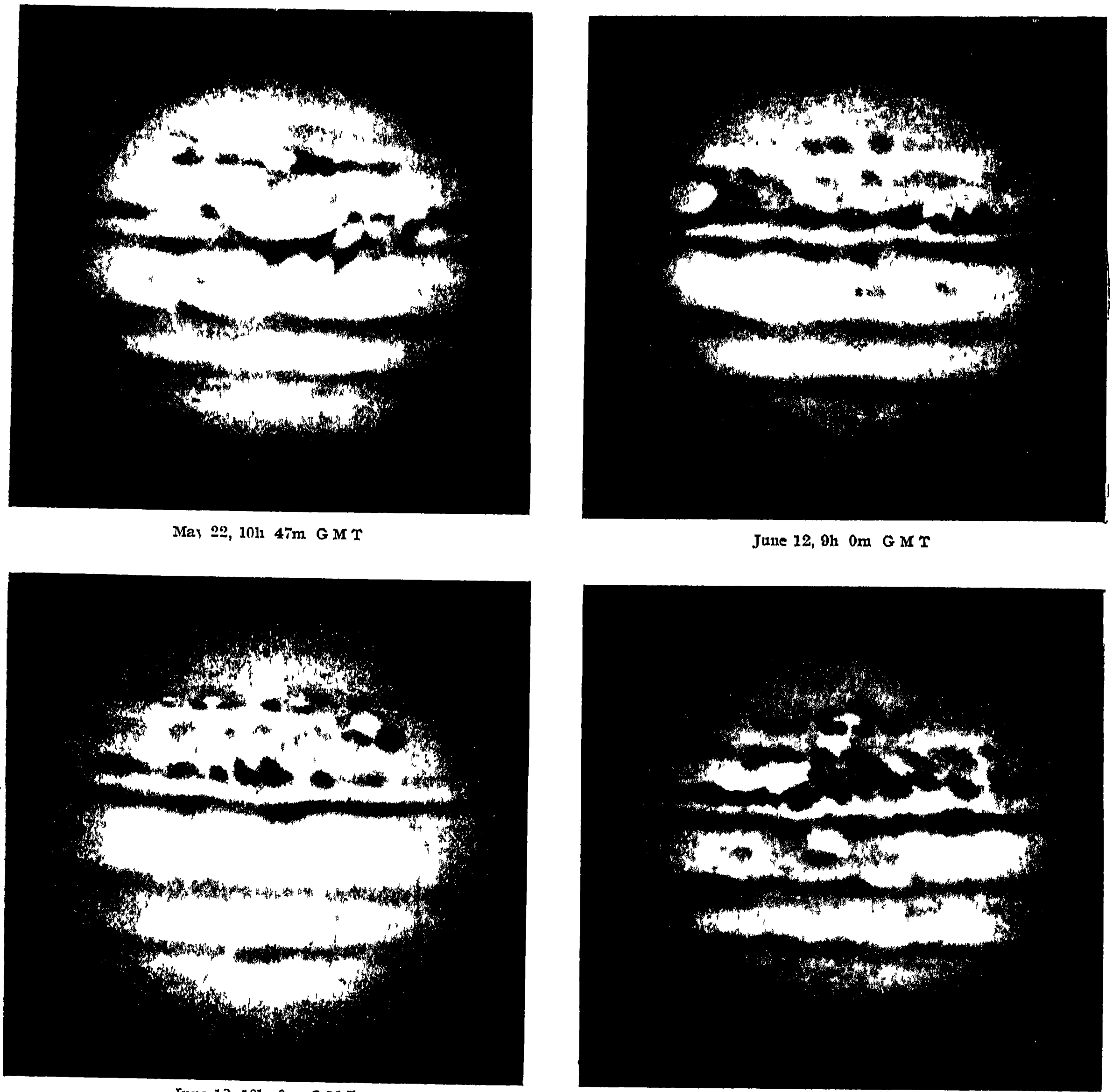
The Satellites of Jupiter — The telescope had only been recently invented when, in January 1610, Galileo discovered four moons attending on the planet This success was one of the very first achievements obtained by an instrument which proved responsible in later years for nearly all the great advances made in Astronomy Its powers have extended the capacity of natural vision a thousand fold, and it has enabled us to perceive myriads of objects and phenomena which were utterly beyond the scope of the unaided vision Galileo announced his early discoveries to a rather sceptical world The newly found moons of Jupiter were disputed, and Galileo had some difficulty in getting satisfactory corroboration He lived in an age of superstition

A list is here given of the nine discovered satellites, and there may be others not yet detected The four discovered by Galileo are considerably brighter than the others and are visible in a field-glass or small telescope The remainder are quite in a different class in regard to size and visibility, and their observation needs powerful means

No as discovered	No in Distance from Jupiter	Star magnitude	Mean distance Miles	Period of Sidereal Revolution D H M	Discoverer	Year
V	1	13	112,500	0 11 57½	Barnard	1892
I	2	6½	261,000	1 18 27½	Galileo	1610
II	3	6½	415,000	3 13 13½	Galileo	1610
III	4	6	664,000	7 3 42½	Galileo	1610
IV	5	7	1,167,000	16 16 32	Galileo	1610
VI	6	14	7,110,000	250 14 40	Perrine	1904
VII	7	17½	7,390,000	260 1 24	Perrine	1905
VIII	8	18	14,940,000	738 21 36	Melotte	1908
IX	9	18½	14,940,000	745 0 0	Nicholson	1914

The four satellites discovered by Galileo were named Io, Europa, Ganymede, and Callisto, by Simon Marius, who claimed to have independently discovered them in December 1609 at about the same

period as Galileo The others have not yet received distinctive names, but are known by Roman numbers applied in the order of their date of discovery Though the ten satellites of Saturn were never lacking in titles yet the Jovian moons have been neglected in this respect This might be considered a very curious irregularity in astronomical nomenclature, but it is explained by the fact that Simon Marius, who named four of the satellites, was regarded as a fraudulent claimant to their discovery, and it was considered that the adoption of his names might be thought an admission of his asserted priority In recent years, however, the names have been coming into such frequent



May 22, 10h 47m G M T

June 12, 9h 0m G M T

June 12, 10h 0m G M T

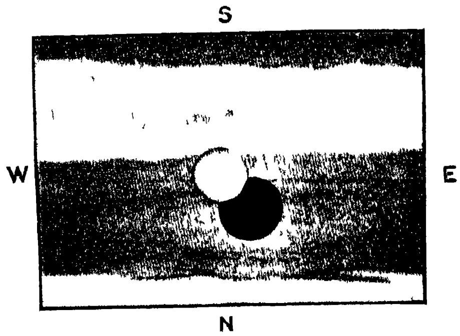
July 13, 8h 40m G M T

E M Antoniadi] [Memoirs of B A A

JUPITER IN 1911

These drawings, made with the thirty-two-and-three-quarter inch refractor of the Meudon Observatory, give a good idea of the complexities of Jovian detail as revealed by powerful instruments, indeed, it is a common experience among observers of Jupiter to see far more detail than can possibly be recorded in the short time allowed by the planet's rapid rotation It will be noted that, in this year at least, the Southern Hemisphere showed signs of far greater activity than the Northern

use that their general adoption appears imminent. And it will be an innovation of a desired kind when the other satellites are dignified by the application of specific titles. It may be mentioned here as a singular fact that, though the four known satellites of Uranus have received names, the solitary moon of Neptune is still a nameless orb.



E. E. Barnard] [From M.N., R.A.S.

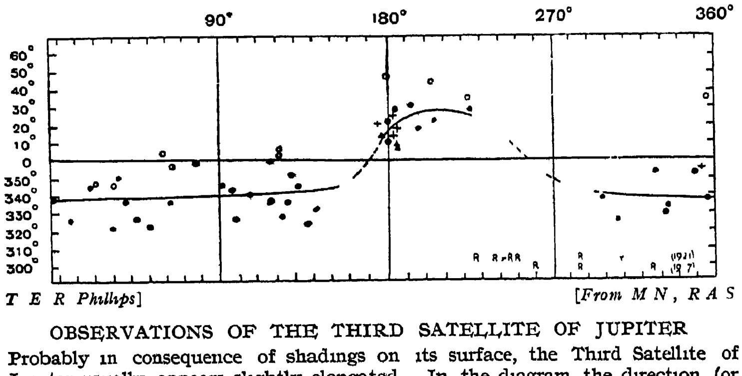
TRANSIT OF JUPITER'S FIRST SATELLITE AND ITS SHADOW

The first and second Satellites appear as bright discs when seen projected against the darker belts of Jupiter. With powerful telescopes a white band has often been observed crossing the disc of the First Satellite, as shown in the illustration above.

Galileo's moons are to be reckoned among the principal objects to be observed by the amateur astronomer. They provide a number of interesting configurations from night to night and their relative positions change from hour to hour. They are usually placed nearly in a line with the directions of the belts and the planet's equator. Sometimes three may be on the west side and one on the east; at other times the distribution may be equal or possibly they may all be placed on one side at the same time. One or more of them may be eclipsed in the shadow of the planet or occulted behind his globe, or in transit across the disc of its primary and situated between the Earth and planet. On such occasions we may perceive the shadows of the satellites as black spots in transit. These phenomena are excellently visible with moderate means. When a satellite begins its transit it is seen on the edge of Jupiter's disc as a brilliant spot, but it is gradually transformed as it moves well on to the disc into a dark spot. This applies specially to the third and fourth satellites, and is sometimes true of the first satellite, but the second satellite seems to possess greater reflective power than the others. Its shadow when projected on Jupiter's surface has been stated to be of a chocolate colour and is not nearly so black as the other shadows.

The velocity of light was first measured by Romer in 1675 from observations of the eclipses of the satellites, for it was found that these phenomena occurred sometimes earlier and sometimes later than predicted, the difference being attributable to the varying length of path traversed by the light of the satellites, according as the Earth was nearer to or farther from them. Romer erroneously deduced a value of twenty-two minutes for the extreme difference, and the true size of the Earth's orbit was in his time imperfectly known. However, his observations and data were sufficient to show that the velocity of light was of the order of 200,000 miles per second. The true value is now known to be 186,325 miles per second, and light crosses the Earth's orbit in sixteen minutes and thirty-seven seconds.

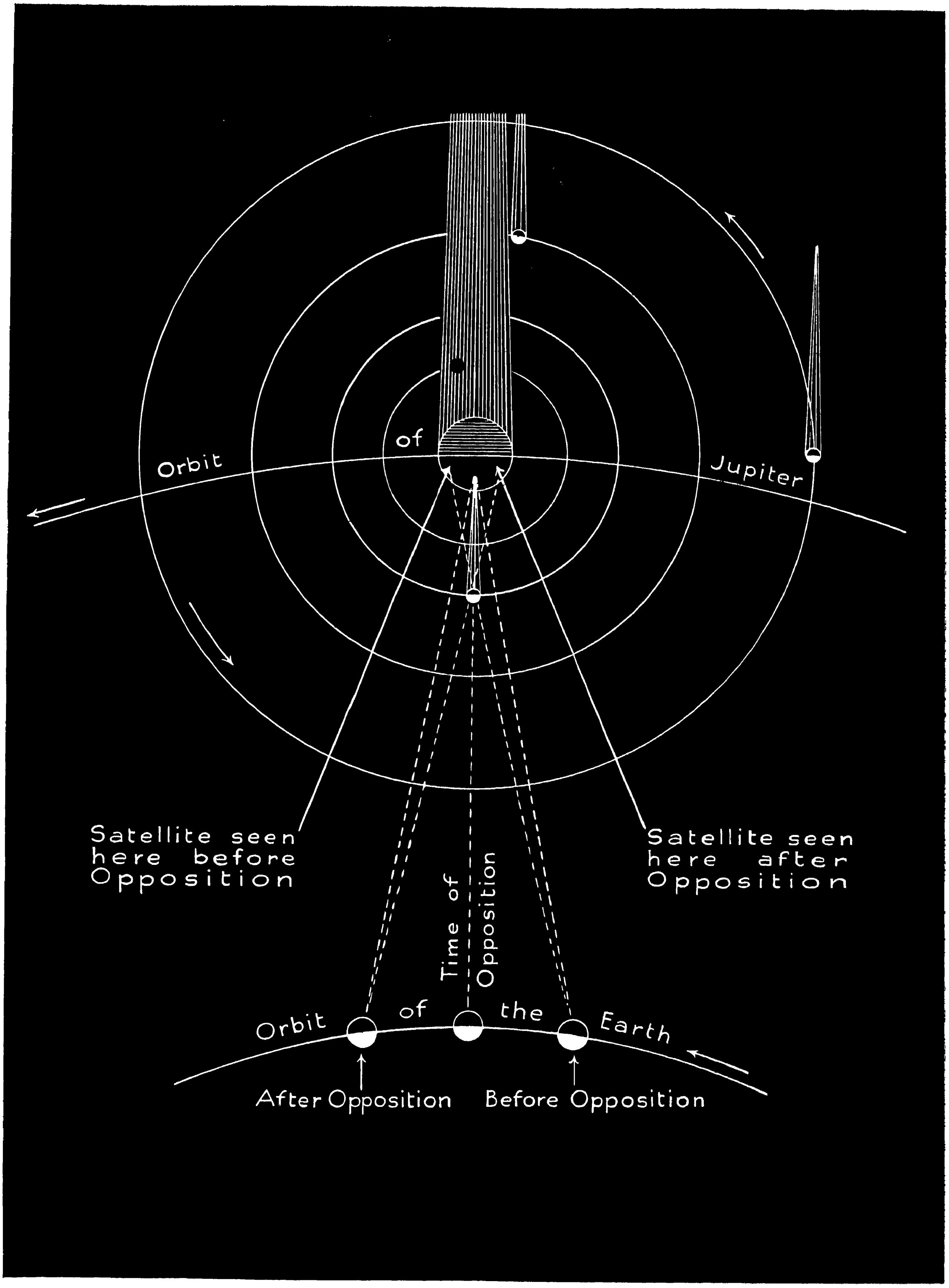
Spots have been observed on some of the satellites, and especially on the third, which is much the largest, and has a real diameter of about 3,550 miles. Dawes saw the markings on this satellite in 1849, and Lassell and others since his time have also recognised them. Barnard discovered what appeared to be a dark equatorial belt on the fourth satellite, and thought it might be duple, but this has not been confirmed. Oval forms have also been attributed to the satellites by various observers. Innes, Phillips and others have made observations, especially of the third and largest satellite, which suggest that, like our Moon, it



T. E. R. Phillips] [From M.N., R.A.S.

OBSERVATIONS OF THE THIRD SATELLITE OF JUPITER

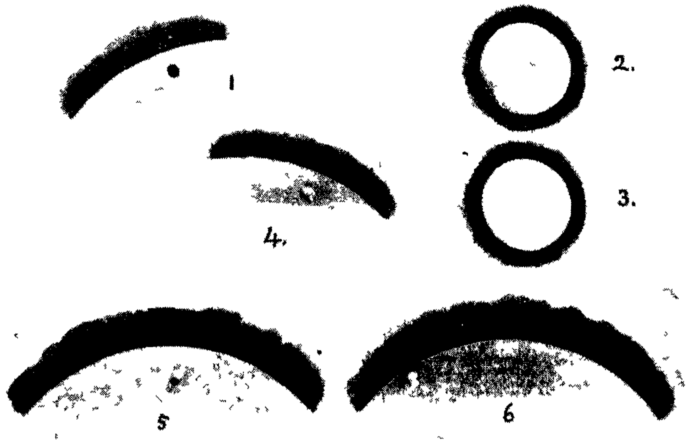
Probably in consequence of shadings on its surface, the Third Satellite of Jupiter usually appears slightly elongated. In the diagram the direction (or position angle) of the largest diameter is plotted against the place of the Satellite in its orbit, reckoned in degrees from superior geocentric conjunction, i.e., when it is behind the planet. It will be seen that the changes are systematic, from which we may conclude, as has been suggested by Innes and others, that, approximately at any rate, the Satellite turns the same face to Jupiter as our Moon does to the Earth. No elongation is seen between 225 and 300.



ECLIPSES AND TRANSITS OF JUPITER'S SATELLITES

The orbits of Jupiter's larger Satellites lie so nearly in the same plane as the Earth's path round the Sun that most (and often all) of them appear to us to pass at each revolution both in front of and behind their primary In the former case they are said to be in "transit," and at such times each throws a little round black shadow on the bright surface of the planet These shadows appear in advance of, close to, or behind each Satellite, according to the relative positions of the Sun, Earth, and Jupiter When on the other side of Jupiter, the Satellites are plunged into his great cone of shadow and become invisible by eclipse It will be seen from the diagram that they may also be hidden from us by the body of Jupiter, though not in his shadow They are then said to be "occulted"

rotates on its axis in the same time as that in which it revolves in its orbit, so that it turns always the same face to the planet Occasionally the four brighter satellites have been invisible at the same time, being either in transit or hidden in eclipse or occultation This was the case in November, 1681, May 23, 1802, September 27, 1843, August 21, 1867, and on several subsequent dates

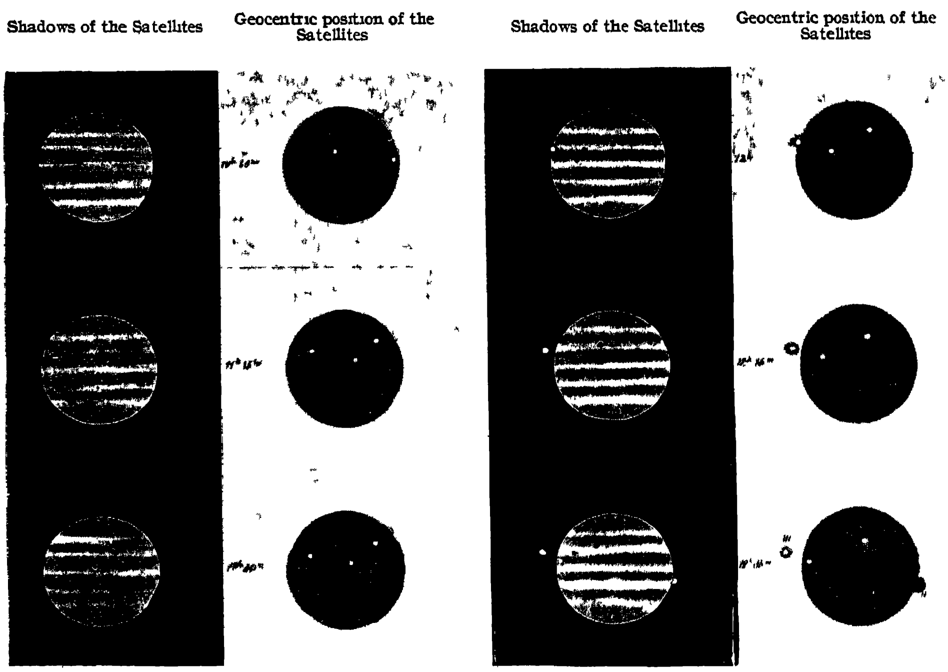


T E R Phillips and W H Steavenson] [*Journal of B A A*

JUPITER'S THIRD SATELLITE IN TRANSIT

Satellites in transit often appear of an abnormal shape, and this is due to the combined effect of markings on their surfaces and the general tone of those parts of the planet against which they are seen The transit depicted above occurred on 1917, October 1, and the sketches marked 2 and 3 (each by a different observer) show the markings on the Satellite responsible for the appearances shown in 4, 5, and 6 Sketch No 1 represents the shadow of the Satellite

The question as to whether any of the satellites can be distinguished with the unaided eye has been much debated The instances of affirmative testimony are pretty numerous and appear to be reliable, but some scepticism still exists on the point It is argued that the moons are so near to the planet that they are involved in his rays, and moreover, being of small magnitude, must be overcome by the light of their primary When, however, the third and fourth satellite are near their elongations and on the same side of the planet, it is sometimes possible for a keen-sighted person to obtain glimpses of them as one No doubt a few of the observers who claim to have performed the feat have been victimised by illusion or imagination, but it seems quite within the powers of the human eye



TRANSITS OF SATELLITES AND THEIR SHADOWS, 1867, AUGUST 21 (*Tempel*)

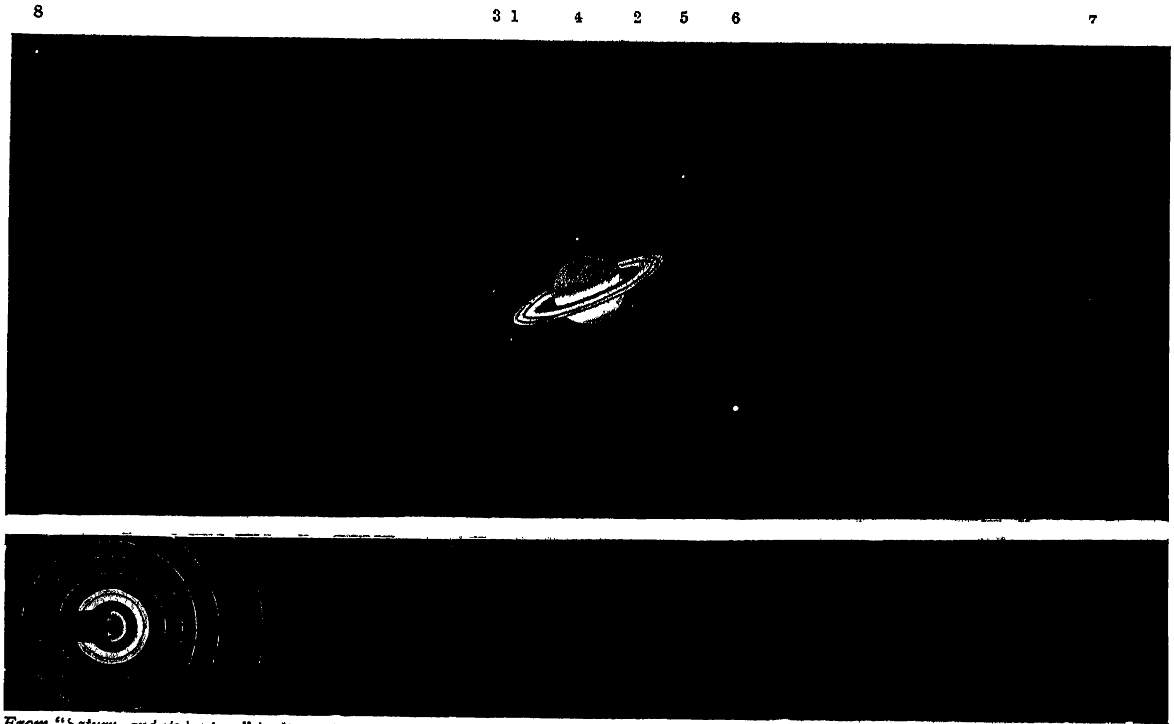
When, as sometimes happens, more than one satellite is seen in transit at one time, a very striking spectacle is afforded The shadows are always prominent, though of slightly differing size and sharpness, but the satellites themselves are not always easily distinguished Apart from their real differences of surface brightness, they are affected in their appearance by contrast with the portion of the planet (light or dusky) against which they are seen

SATURN

BY P H HEPBURN, LL B , F R A S

Passing beyond Jupiter, the next planet in order from the Sun, and at nearly twice the distance, is Saturn This is the most distant of those planets that are readily visible to the naked eye, and (as a rule) the faintest in lustre, besides being the slowest in apparent as well as real movement round the Sun Jupiter takes nearly twelve years to complete its circuit of the heavens , Saturn nearly thirty

The ancients recognised that Saturn was the most distant planet known to them They endowed him, in the jargon of Astrology, with the attributes we still speak of as " Saturnine ", dulness, sluggishness and morose malevolence For his symbol they chose the lustreless and heavy metal lead The



From "Saturn and its System," by R A Proctor] [*By kind permission of Messrs Chatto & Windus*

SATURN AND ITS SYSTEM

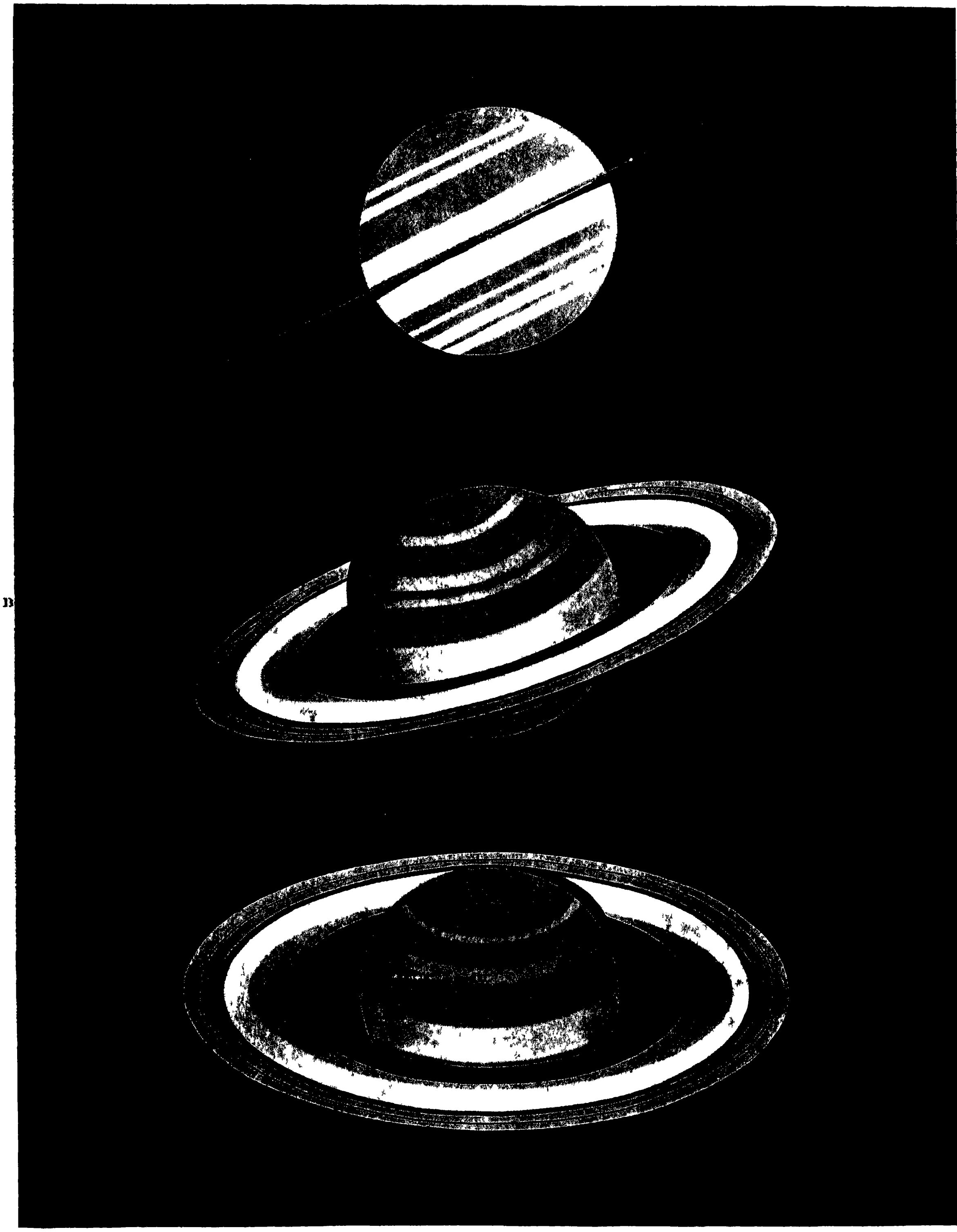
The upper part of this diagram shows an imaginary telescopic view of the planet, with its rings and the eight inner satellites The latter can be identified by the numbers in the margin The lower part shows the rings and satellite orbits to scale The names of the satellites and their distances from Saturn in miles are as follows —

1 Mimas	117,000	2 Enceladus	157,000	3 Tethys	186,000	4 Dione	238,000
5 Rhea	332,000	6 Titan	771,000	7 Hyperion	934,000	8 Iapetus	2,225,000

The distance of the ninth satellite " Phœbe " is 8,096,000 miles

contrast with the reality is striking Far from being heavy and leadlike, Saturn is the lightest in substance among the planets Instead of sluggishness being his attribute, we find his surface conditions even more turbulent than those of Jupiter, while the telescope discloses this dull and lustreless planet as perhaps the most purely beautiful object in inanimate nature

In many respects Saturn presents well marked analogies to Jupiter In each case we have a vast globe, flattened at the poles, and in very rapid rotation Saturn is but little less in diameter than Jupiter, and somewhat more bulging at the equator Jupiter has a large family of satellites, so has Saturn So far, the planets are alike , now we come to the great point of difference In the case of Saturn we have also to contemplate the mysterious and beautiful ring system, which has no analogue



From "Saturn and its System," by R. A. Proctor] [*By kind permission of Messrs. Chatto & Windus*

SATURN AND ITS RINGS

Three ideal views of Saturn as seen in a very powerful telescope, at the phases of minimum and maximum opening of the rings, and an intermediate phase. The inclination of Saturn's axis to its orbit plane is 26° 49′ 5, but owing to the inclination of the planet's orbit to the ecliptic the inclination of the planet's axis as seen from the Earth is sometimes as much as 27° 13′. This is the position shown in the lower diagram. Encke's Division in ring A is not usually seen as such a hard line as here represented. The reality of the Divisions shown between rings B and C and in ring C is very dubious. Below are shown the relative sizes of Mars, the Earth, Venus and Mercury on the left, and conjectural dimensions of the satellites on the right.

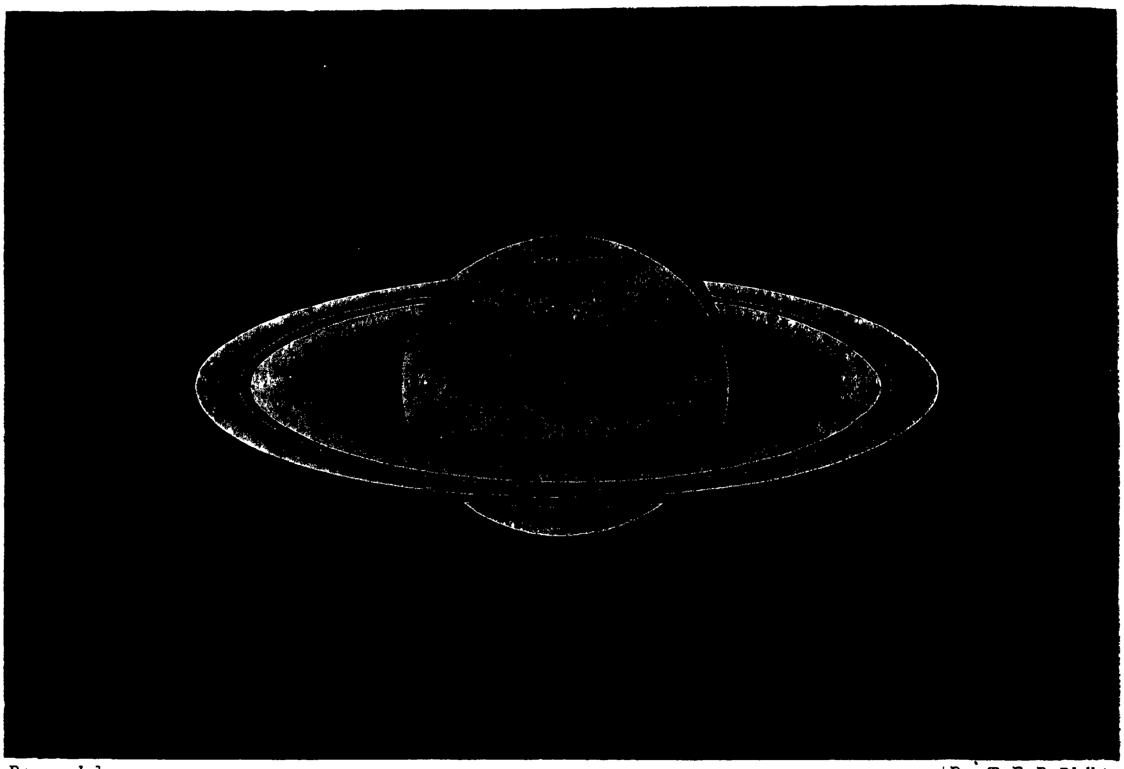
in the system of Jupiter, and indeed is absolutely unique so far as our limited knowledge extends. A good deal of what we have been told about Jupiter and his satellites is probably applicable to Saturn, and we may infer from the analogy of Jupiter much that we cannot observe. We may, therefore, in dealing with the globe and satellites content ourselves for the most part with pointing out such differences as we can perceive, dealing more fully with the planet's unique appendage.

If we compare Saturn with the Earth, we find a curious numerical coincidence which is quite accidental, but may perhaps be mentioned as an aid to memory. In round figures, the distance of Saturn from the Sun is nine and a half times the Earth's, his mean diameter is a little less than nine and a half times the Earth's and his mass ninety-five times the Earth's.

SATURN AND THE EARTH: RELATIVE DIMENSIONS

The following are the approximate dimensions:—*Globe of Saturn*: Equatorial diameter, 75,100 miles; Polar diameter, 67,200 miles. *Ring System*: Over all span of rings, 169,000 miles; breadth of separate rings—A, 10,100 miles; B, 16,500 miles; C, 9,800 miles. Cassini's Division is about 1,700 miles in width and the gap between the planet and ring C about 8,800 miles. These dimensions correspond to the measures used in the ephemerides. Cassini's Division and ring C are probably somewhat wider than as stated.

The relation between the figures for diameter and mass brings us to the most striking physical characteristic of the planet, the exceeding lightness of his substance. For if the diameter of Saturn were exactly nine and a half times the Earth's, the volume of Saturn would be 850 times the Earth's (the actual figure is about 760 times) and if the two planets were made of matter of the same density, the mass as well as the volume of Saturn would exceed the Earth's in the same proportion. But the mass of Saturn is only ninety-five times that of the Earth instead of 760 times, so that the stuff of which Saturn is made is only about one-eighth as dense as the Earth's substance.



Drawing by] [*Rev T E R Phillips*

SATURN, JANUARY, 1911

This drawing shows Encke's Division among other features The author remarks of it "It was never dark like Cassini's Division, but appeared like a delicate pencil shading I do not think this feature is illusory, though it is evidently not a real division and is probably inconstant" The shadow of the outer edge of ring A is seen on the ball

Saturn is, in fact, about thirty per cent lighter than water, and indeed it is lighter than any known solid except the rare metal lithium Of ordinary earth-stuff we find nothing that is so light as Saturn, not even the spongy rock called pumice which floats on water The only familiar solid inorganic substance that is less dense than the substance of Saturn is new-fallen, unpacked snow, and a snowball not too tightly squeezed might be made to approximate pretty closely to the average consistency of this planet We speak of "average consistency," but it must not be forgotten that the stuff deep down in Saturn must be considerably denser than his average which makes the density near his visible surface so much the less

This state of things presents a great puzzle Of what sort of stuff can Saturn be made? No really satisfactory answer has ever been given to this question, which indeed has hardly been seriously tackled The most generally accepted explanation is that in great part, at all events, Saturn is not solid at all, but a heated mass of gas On this hypothesis the planet is, in fact, sunlike, though not so fiercely hot as the Sun, and what we see is the upper surface of the non-luminous vapours floating above the incandescent gaseous interior The behaviour of the satellites lends support to the suggestion that a considerable part of the mass of Saturn is strongly condensed towards his centre If this is the true explanation, we would like to know, in addition, why Saturn is so considerably lighter, bulk for bulk, than Jupiter, to whom similar considerations must be supposed to apply Jupiter is twice as dense as Saturn

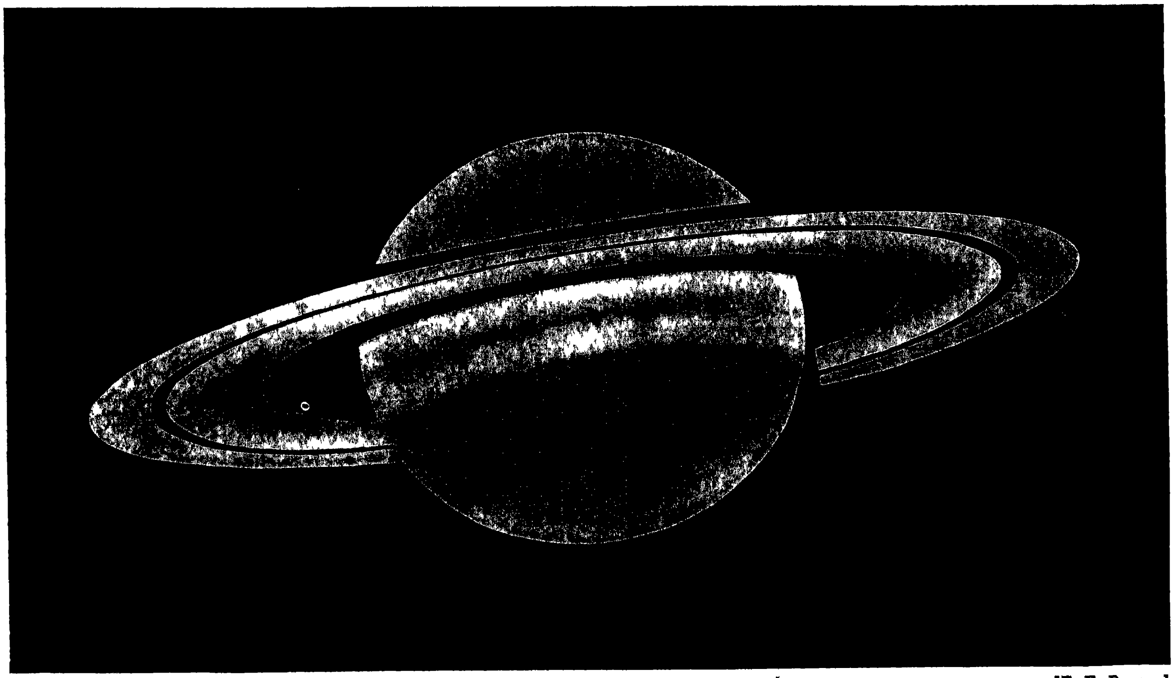
The relation between speed of rotation and equatorial bulge is significant in this connection Other things being equal, the faster a planet rotates the greater will be the bulge Now Jupiter, with a diameter of 88,700 miles, rotates in about nine hours fifty minutes Saturn, with a diameter of 75,100 miles, in about ten hours fifteen minutes So that the equatorial speed of rotation of Jupiter is over 28,300

miles an hour, that of Saturn only 22,000 miles an hour And yet the equatorial bulge, the fraction of itself by which the equatorial exceeds the polar diameter, is one-fifteenth in the case of Jupiter, it is one-tenth, *i e*, fifty per cent more, in the case of Saturn

In contradiction to the heat hypothesis, it has been recently suggested on physical grounds that Saturn, Jupiter and the other outer planets must be colder than the interior planets, and if this is so, the matter is more mysterious than ever Some evidence that the real globe of Saturn is smaller than we see and that he is surrounded by a very deep atmosphere may perhaps be found in recent observations by Instructor Captain Ainslie and Mr Knight of the passage of Saturn over a star Both the disappearance of the star behind the limb of the planet and its subsequent re-appearance were slow and gradual, and took a length of time estimated in minutes, instead of being instantaneous as we should expect We should, however, perhaps be wrong to attach too much importance to this observation

Whether Saturn has a solid surface or not, it is certain that what we see is not solid, but the upper surface of clouds of some sort—either floating in the planet's atmosphere or supported by radiant forces due to internal heat We need not, however, suppose that these clouds are necessarily formed of water or ice, as are the clouds that float in our own atmosphere As in the case of Jupiter, this visible surface is diversified by shifting belts and occasionally by spots Since, however, Saturn, owing to his greater distance from the Sun, is much less strongly illuminated than Jupiter, and owing to his greater distance from the Earth is seen on a considerably smaller scale, very little detail can be made out beyond the broadest general outlines In fact, on only about half a dozen occasions have spots been seen which could be " held " by observers of ordinary acuteness of vision so as to enable the rotation period of the planet to be determined

The first such observation was made by Herschel in 1793, and from it he deduced a rotation period of ten hours sixteen minutes, showing a velocity of rotation not quite so rapid as Jupiter's Subsequent observations of a similar nature indicate that as in the case of Jupiter (and also of the Sun)



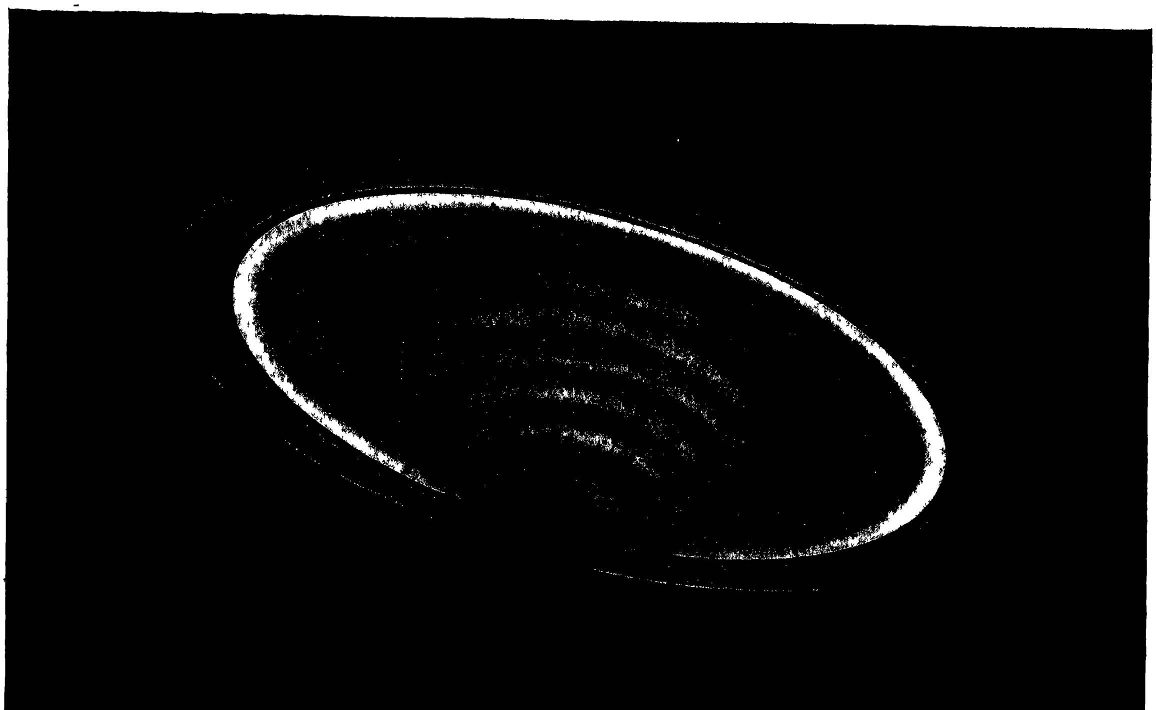
By permission of R A S] [*E E Barnard*

SATURN, JULY 2, 1894

A drawing made at the great telescope of the Lick Observatory The observer remarks —" I have only drawn what I have seen with certainty It is true the picture appears abnormally devoid of details when compared with drawings made with some of the smaller telescopes I am satisfied, however, to let it remain so "

there are different rates of rotation in different latitudes These differences are in Saturn's case even more marked than in Jupiter's, implying surface currents of something like 900 miles an hour At Saturn's great distance from the Sun, it is very difficult to see how the solar energy can be sufficient to create these great movements, and we seem driven again to the hypothesis of internal heat to explain them

Pictures of Saturn often show more diversity of marking than the description we have given above would imply We must remember, however, that the detail shown in these pictures is, generally speaking, only glimpsed at moments of the most perfect seeing, and then only by exceptionally keen-eyed observers In attempting to draw such detail it is necessary to exaggerate contrast very greatly The colours shown in illustrations of Saturn are often but little exaggerated There are moments, though they are rare, when the delicate tints of Saturn present a spectacle of amazing beauty

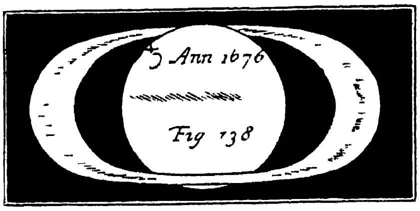


By permission of R A S] [*E E Barnard*

SATURN, JULY 7, 1898

Another of Barnard's magnificent drawings, made at the Yerkes forty-inch refractor The author remarks "I have never seen the planet better, nor have I seen so much detail upon it before There seems to be a dusky shading where Encke's Division is usually shown" This drawing (like the last) is of great value as showing what a pre eminently skilled observer, using the most powerful refractor in existence, could see on an exceptionally favourable occasion

The satellites of Saturn form a system not less interesting than Jupiter's Jupiter has four large satellites, one small, and four which we may call minute In Saturn's case, we have three comparable with Jupiter's greater satellites, namely Titan, which is considerably larger than our Moon, and Rhea and Iapetus, each of which may be about a thousand miles in diameter We have next a series of five of what we may call moderate size, ranging from 800 or 900 miles to 200 or less Then we know of one very distant minute satellite of the same order of size as the four outer satellites of Jupiter This body, to which the name "Phoebe" has been given, was observed by W H Pickering (on a photograph) in 1898 It is computed to be about fifty miles in diameter If Saturn were no farther off than Jupiter, we should doubtless be able to see more of these little bodies Indeed the discovery of another one was actually announced by Pickering soon after that of Phoebe, but its existence has not been satisfactorily confirmed Except in the case of Titan, the dimensions we have given for



[J D Cassini

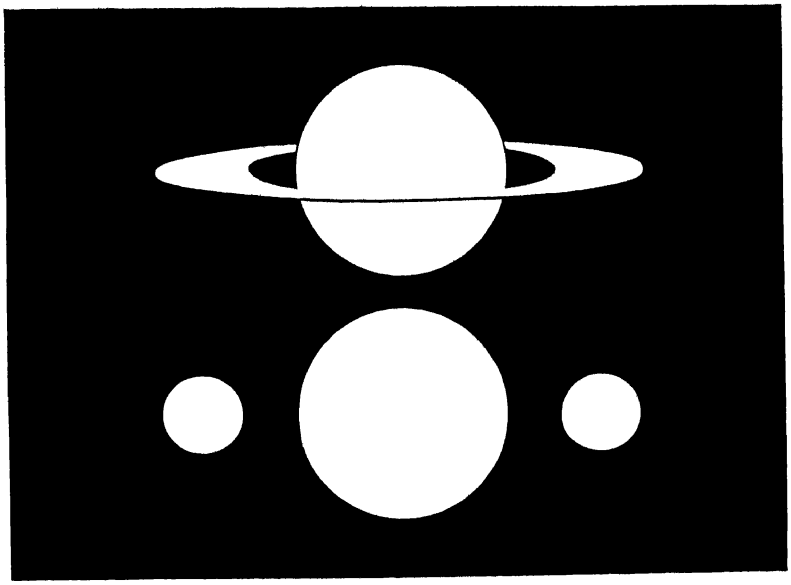
AN EARLY DRAWING OF SATURN
This sketch of Cassini's, which is dated 1676, is of interest as being the first published drawing which shows the great "Division" in the ring

the satellites are highly conjectural, as owing to their great distance they are too small for direct measurement

When the motion of Phoebe was studied by its discoverer, a surprise developed He found that this motion was "retrograde," and therefore in contrary direction to those of the inner satellites and of the planet's own rotation A similar state of things exists with regard to the outermost satellites of Jupiter, but they were not discovered until later It is curious that Saturn, whose rings furnished a hint which probably had a great deal to do with the formation of Laplace's celebrated "Nebular Hypothesis," should be the first planet to deal a shrewd blow to that hypothesis by exhibiting contrary motions of revolution in one and the same system

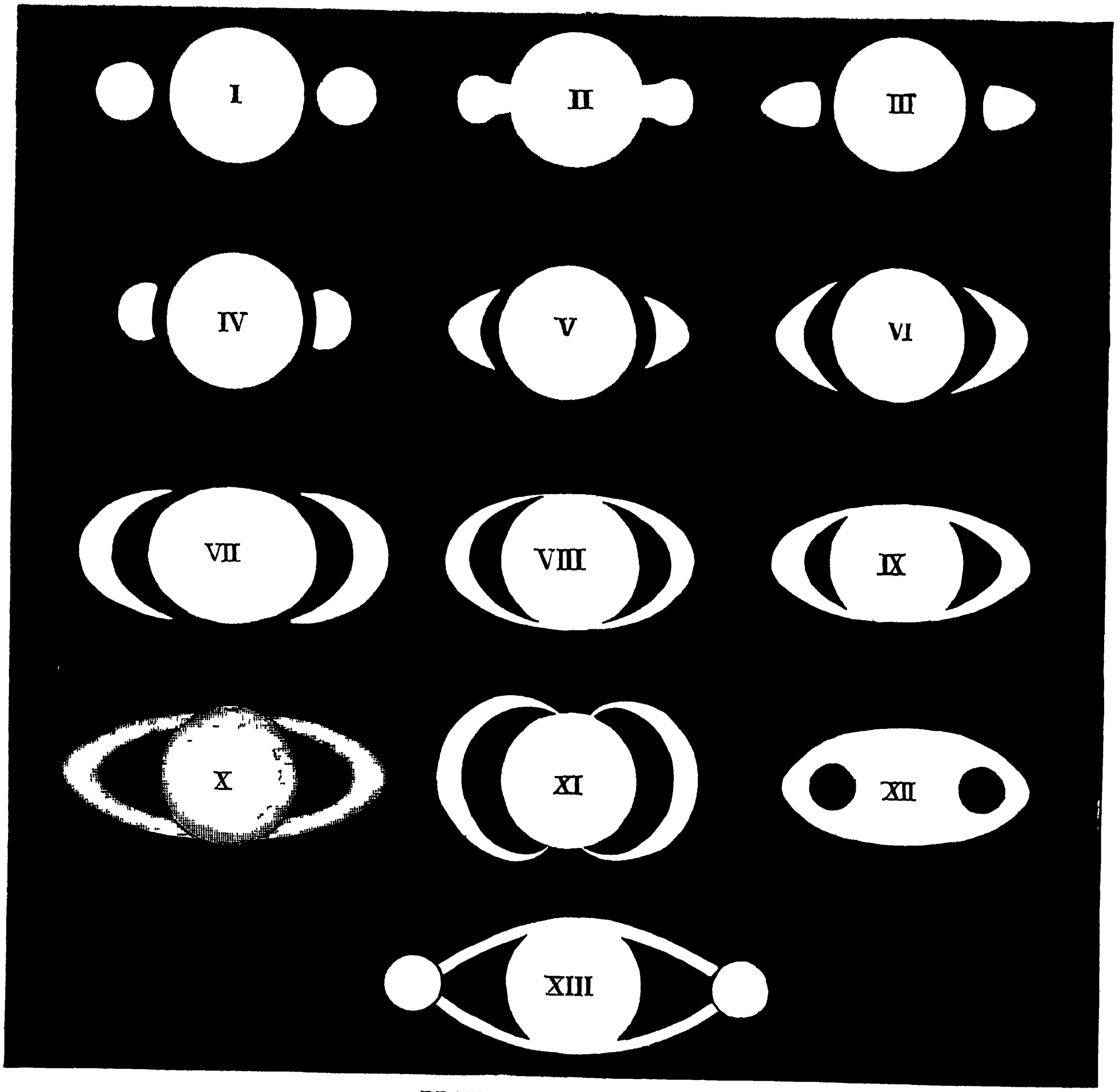
From the regular variations of light of some, if not all, of the satellites of Saturn, it is believed that they always turn the same face to their primary, as does our own Moon This is very noticeable in the case of Iapetus, the outermost of the eight large satellites, so noticeable that Huyghens, by whom this satellite was discovered in 1671, was even at that early date able to observe the fact and to suggest the reason There is reason to believe that some of the smaller satellites of Saturn, or at any rate Mimas the nearest, are even lighter in substance than the planet itself They are also remarkable for their high "albedo" or whiteness (see page 104) which would seem to be comparable with that of snow Owing to their small size, we cannot, as in the case of the planet itself, suppose that they are expanded by internal heat, or that they are cloud covered—bodies so small could not retain atmospheres It appears to the present writer, as a possibility worth consideration, that these satellites may be composed of ice, or perhaps to some extent of loosely packed snow or some similar substance It seems the only way of accounting for their lightness and whiteness

Let us now pass to consideration of the wonderful ring system which is the distinguishing feature of this planet The general aspect is probably familiar to everyone, whether he has looked through a telescope or not A small telescope shows Saturn encircled by "a flat ring nowhere touching the planet," to use the words of Huyghens, who first observed the true nature of this appendage A good three-inch telescope shows in addition a fine black line traced round the surface of the ring, suggesting that there are, in fact, not one but two rings, one within the other Cassini in the Seventeenth Century was the first to call attention to this line and it is called, after him "Cassini's Division" A similar line can be seen when the other face of the ring is turned toward us, but it was left to Herschel more than 100 years after the discovery to establish by exact measurement that the two lines are really one, and, in fact, represent a real division and not merely surface markings



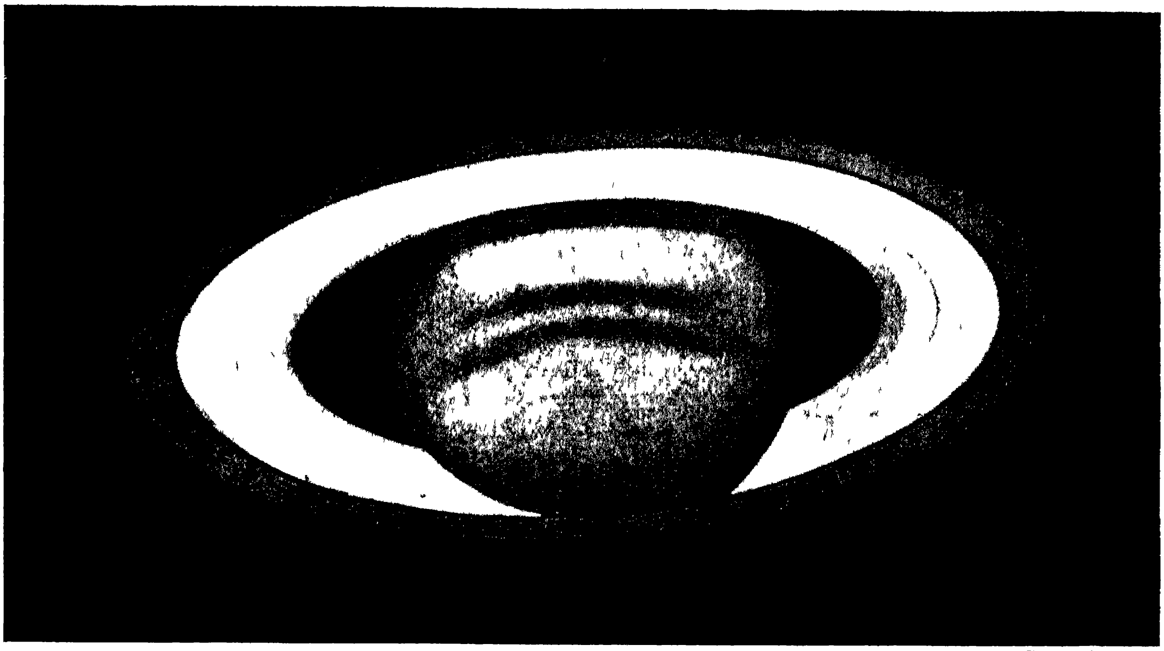
GALILEO'S FIRST VIEW OF SATURN
The upper part of this diagram shows roughly the aspect of Saturn in 1610 Galileo's telescope was sufficiently powerful to show the broad extremities of the ring ellipse but not the narrow parts nearer the planet His interpretation of what he saw—a triple planet—is shown beneath

A more powerful telescope shows us clearly that the two rings (usually called "A" and "B," A being the exterior of the two) are not uniform in brightness, B is brighter than A and the outer region of B (which is the brightest portion of the Saturnian system) is brighter than the inner region It also shows us another marvel Within ring B is a third ring of fairylike delicacy, and transparent, so that the edge of the planet can be seen through it It is beautifully represented in the illustration on page 362 It is called ring C, or, from its filmy transparency, the "crape ring" This ring is easy to see in quite small telescopes as a dark shading where it crosses the planet, and is, in fact, clearly shown in some of Herschel's drawings The German astronomer Galle was the first to recognise this ring in 1838, but his observation very curiously remained unnoticed and the discovery of the crape ring as such is usually attributed to the American Bond and our own Dawes in 1850 The history of this ring is a curious example of how a phenomenon may stare astronomers in the face



DRAWINGS OF SATURN

Sketches made by divers early observers of the seventeenth century before the true nature of the ring was perceived by Huyghens These drawings are interesting as showing the capacities of the early telescopes before the discovery of the achromatic principle With the modern achromatic three inch telescope the true figure of the ring is immediately apparent



By permission of R A S] [E M Antoniadi

SATURN, JUNE AND JULY, 1899

Showing the rings at their greatest opening Besides Encke's Division in ring A a well marked " division " was observed in ring B Both " divisions " are drawn as fine lines, but as in the case of the canals of Mars, some doubt may be felt as to whether these objects are really of this nature The drawing shows irregularities (rarely observed) in ring A

and yet remain undetected In the winter of 1907–1908 certain observers thought that they had detected a very faint dusky ring exterior to ring A, but its actual existence cannot be considered as established

Cassini's Division is always obvious and its nature is undoubted Other similar markings have occasionally been observed in all the rings, some of which possibly represent real, though not necessarily permanent, divisions The least difficult of these and the one most often perceived is " Encke's " Division, in ring A It may be, however, that the so-called division is really a mere difference of shade as it appears in some of our illustrations We have already seen, when dealing with Mars, that what to some eyes appears to be the boundary of a shading, is seen by others as a fine line Some of the keenest-sighted astronomers, using instruments of every size up to the most powerful refractors in existence, have but seldom perceived more than a doubtful indication of Encke's Division

Before we pass to the question of the physical constitution of the ring system, it will be useful to consider for a moment its changes of aspect Ever since telescopic observation of Saturn began, the planet has been in the habit of springing surprises on astronomers The first observer, Galileo, found that the planet seemed to be triple—a big globe in the middle and what looked like a little globe on each side This astonished him, and he was still more astonished rather more than a year later, when he looked at the planet again and found that the two smaller globes had vanished " Has Saturn then," he said, " devoured his own children ? "

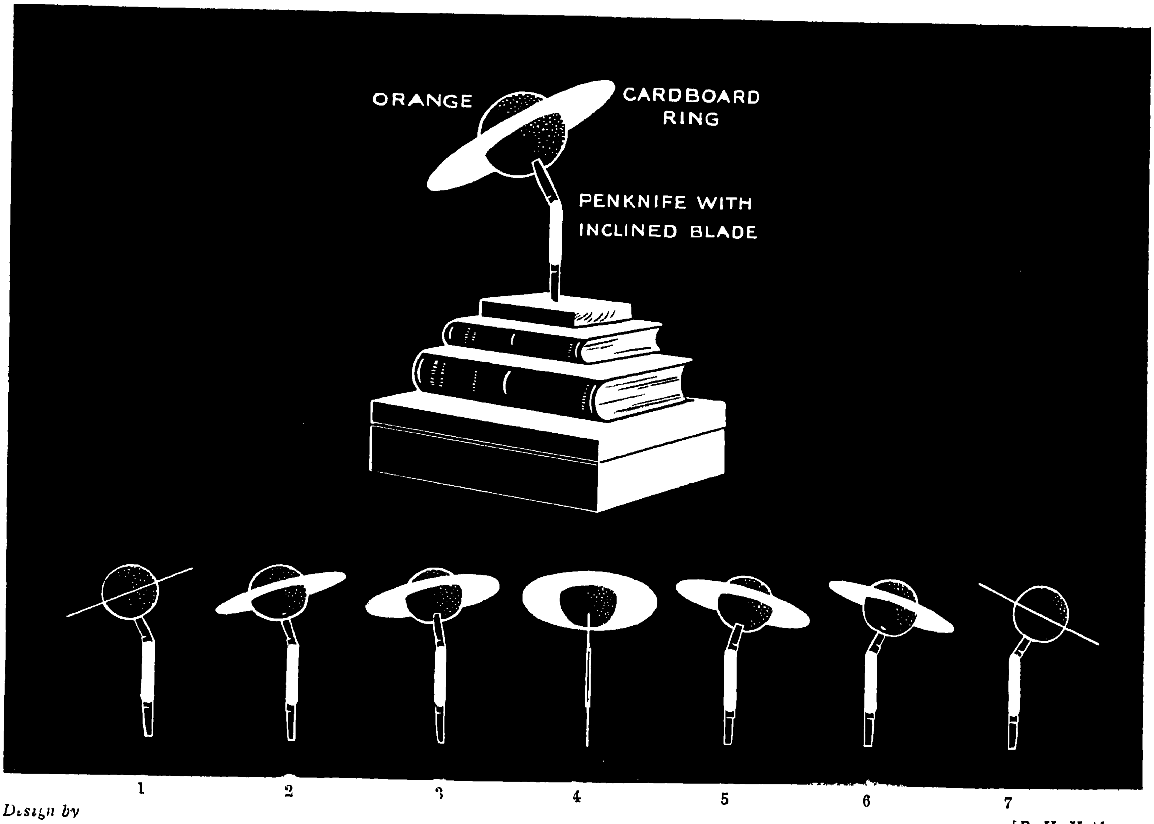
To understand what has happened it is well to make a rough model (see page 366) which may be done as follows —

Cut out a circular piece of stiff cardboard six inches in diameter Spear it on the small blade of a pocket knife wedged open to an angle of about twenty-seven degrees Open the other blade fully and stick it vertically in a block of wood, which prop up on a table in the middle of the room until it is at the same level as the eye Find the position where the cardboard disc is seen exactly edgewise as in (1), then on proceeding round the room, still keeping the eye at the same level, the disc will be seen in the several positions (2), (3), (4) and so on, until we return to (1)

During half this circuit, we shall see the top side of the disc, say the north side, and during the other half, the under, or south side At two positions the disc will be seen edgewise and if it were very thin, it would vanish At two others, it will be seen at maximum opening

Of course, in reality, the observer does not go round Saturn, Saturn goes round the observer But the result is precisely the same, in either case, and it is easier to walk round the model than to cause the model to walk round us

A more elaborate but even more instructive model may be made with a tennis ball, three knitting needles and a cardboard ring The ring should be cut out to scale with the ball according to the dimensions given later By treating this model in the same way as we did the disc, we shall reproduce the actual phases of the planet as illustrated on page 103



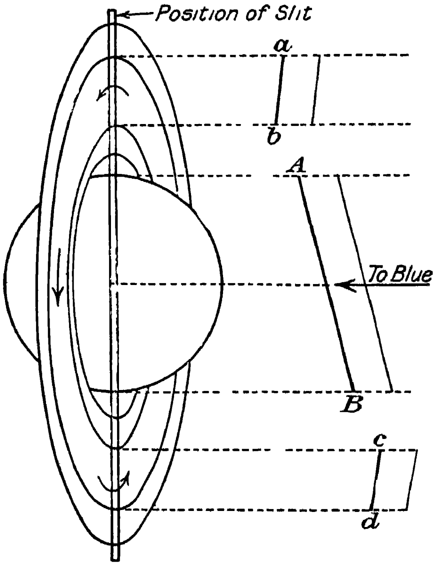
Design by [*P H Hepburn*.

MODEL TO SHOW THE PHASES OF THE RING

This model and its uses are explained on page 365 (The artist has inserted an orange, which is perhaps an improvement) The diagram in the lower part of the illustration should be compared with that of the actual phases of the planet appearing on page 103

Now we can see what puzzled Galileo When he looked first, the phase of ring was as in the upper part of the diagram on page 364 which his imperfect telescope showed as in the lower part of the same diagram On the second occasion the ring was viewed nearly edgeways, and being very thin he could not see it at all Since the period of revolution of Saturn is nearly thirty years the ring is viewed edgeways at intervals of fourteen or fifteen years The last occasion was the winter of 1920–1921

Now the ring is so exceedingly thin and so exceedingly flat that for a short time about these periods of " disappearance " no telescope will show it This is a very striking circumstance when we consider its vast dimensions Its span is roughly 170,000 miles, and its breadth from the outer edge of ring A to the inner edge of ring C 38,000 miles, and yet its thickness can hardly exceed fifty miles and may be very considerably less



From "General Astronomy" by H Spencer Jones]
[by permission of Messrs Ed Arnold & Co

SPECTROSCOPIC PROOF OF THE ROTATION OF THE RING

Diagram indicating the nature of the spectroscopic proof both that the ring rotates and that it does not rotate as a solid ring but as a cloud of separate bodies If the ring did not rotate the lines *a b* and *c d* would not be inclined If the rings rotated in one piece, so that the velocity diminished from the outside edge, inwards, the inclination of the lines *a b* and *c d* would be in the same direction as that of the line A B

For some 200 years after its discovery, the ring system was generally supposed to be a continuous sheet of solid matter, though as early as the beginning of the Eighteenth Century, it was suggested that it might be a cloud of small bodies About the end of the Eighteenth Century, the great mathematician Laplace investigated the problem of the stability of solid rings encircling a planet He found, firstly, that a ring, if it is to persist, without falling in on to the planet, must be in rotation round it Secondly, that the breadth of such a ring, if it is not to be disrupted under the strains to which it is subject, must be very narrow The two rings of which at that time Saturn's appendage appeared to be composed were much too broad for his theory Therefore he supposed that they must each be made up of a large number of thinner rings separated by divisions analogous to Cassini's Division, but too narrow to be perceived by the telescopes of his day He further suggested that even such narrow rotating rings would be disrupted unless they were eccentrically placed with regard to the planet and also unequally weighted in different parts of their circumference This very artificial theoretical system held the field for over fifty years Doubtless it derived some support from the observation from time to time of real or supposed divisions in the two main rings

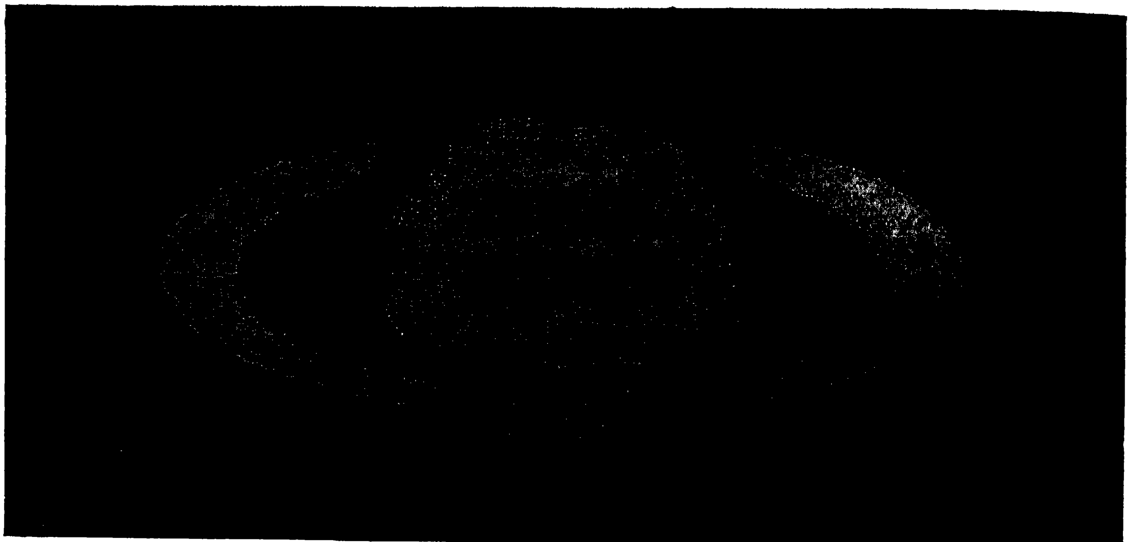
Pierce, an American mathematician, then showed that the rings must be very considerably narrower than Laplace required A little later, in 1857, the English mathematician, Clerk Maxwell, took up the whole investigation afresh He proved conclusively that any continuous solid rings, however narrow, would go to pieces and that it would not help if the rings were fluid, for they, too, would be unstable No alternative was left but to discard altogether the idea that the rings were continuous sheets of matter They could only be flights of small bodies, so small as not to be broken up under the strains to which they are subjected on account of their nearness to the planet

We know as the result of these investigations that the rings of Saturn are made up of discontinuous small particles We do not know certainly the size of these particles except that they are very much smaller than the bodies we usually speak of as "satellites" There are, however, reasons for believing that they are very small indeed, perhaps not larger than the microscopical particles or droplets of which terrestrial clouds are made It has even been suggested that the rings may not be composed

[E E Barnard

PHOTOGRAPH OF SATURN NOVEMBER 19, 1911

The first really good photograph of the planet, taken with the sixty-inch Mt Wilson reflector Four exposures, each of about ten to twelve seconds, appear on the same plate This illustration should be compared with the enlarged copy on the succeeding page It may also be compared with Mr Phillips' drawing (page 360) made in January of the same year



Drawing by] [*P. M. Hepburn*

ENLARGED DRAWING OF SATURN FROM PROFESSOR BARNARD'S PHOTOGRAPH OF NOVEMBER 19, 1911

This drawing enables the features shown in the photograph on the preceding page to be studied more conveniently The crape ring is clearly visible where it crosses the planet, but is too faint to show in the space on each side of the ball The outline of the globe is visible through ring A No shadows appear since the planet was within ten days of opposition

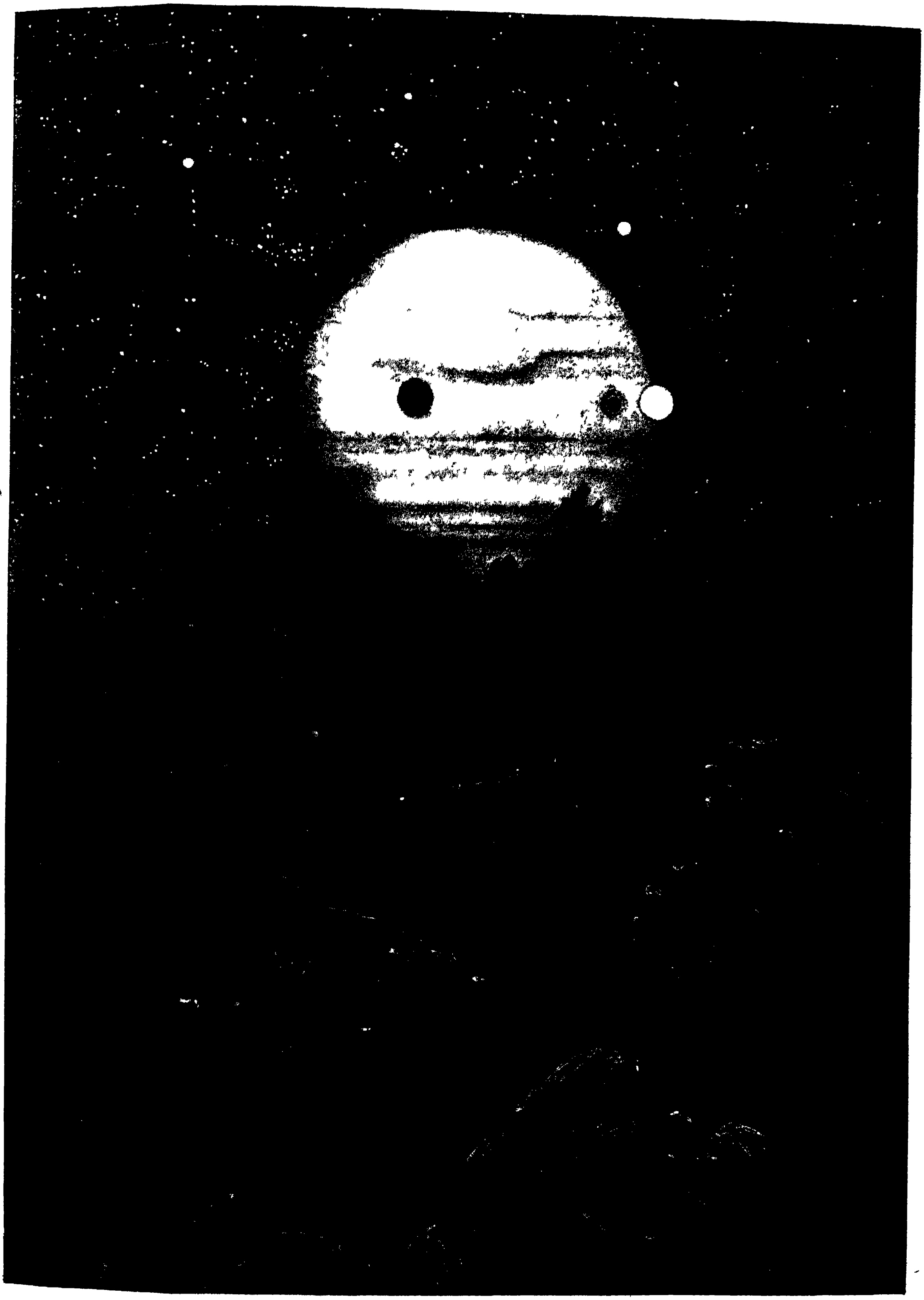
of ordinary atomic matter at all, but that they are a film of " ionised molecules," analogous perhaps to the streams of electrons believed to be shot out from the Sun, but this is perhaps going a little too far

Whatever their size, each such particle must be thought of as revolving round Saturn as an independent minute satellite, at the proper rate corresponding to its distance from the centre of the mass of the planet There is, however, a point about minute bodies that must not be forgotten They would not move precisely like the comparatively heavy numbers of the Solar System with which we are more familiar, under the law of gravitation alone, but they would also be subject to forces arising from radiation pressure which in the case of such bodies might possibly produce more powerful effects than gravitation

That the particles forming the ring revolve round Saturn is certain, but such revolution cannot be visually observed, since the rings present no irregularities that can be followed with the telescope It is true that Herschel thought he had detected a bright point in the ring which appeared first on one side of the planet and then on the other, and he deduced from it a rotation period of ten hours thirty-two minutes, which corresponds to the gravitational period of revolution of a particle near the outer edge of ring B It is probable, however, that what he saw was a certain optical phenomenon which has often since been observed, and which is not attributable to rotation of the ring The fact not only of rotation, but of differential rates of rotation such as are required by gravitational theory has, however, been beautifully confirmed by spectroscopic observations dependent on the " Doppler " principle, explained at page 65

Besides the dynamical proof that the rings are not continuous but are made up of small bodies, their insubstantial nature appears from other considerations In the first place, they have no appreciable mass—Hermann Struve, the Russian astronomer, found as the result of his long investigation of the motions of the satellites, completed some thirty years ago, that if the mass of the rings was as large as one-twenty-seven-thousandth of the mass of Saturn, its effect would be apparent in disturbance of such motions This is an outside limit, the real mass of the rings is probably very much less than the figure stated

Again, it has already been mentioned that the inner ring C is transparent, and recent observations have shown that this applies to the two outer rings also, though in a less marked degree Near



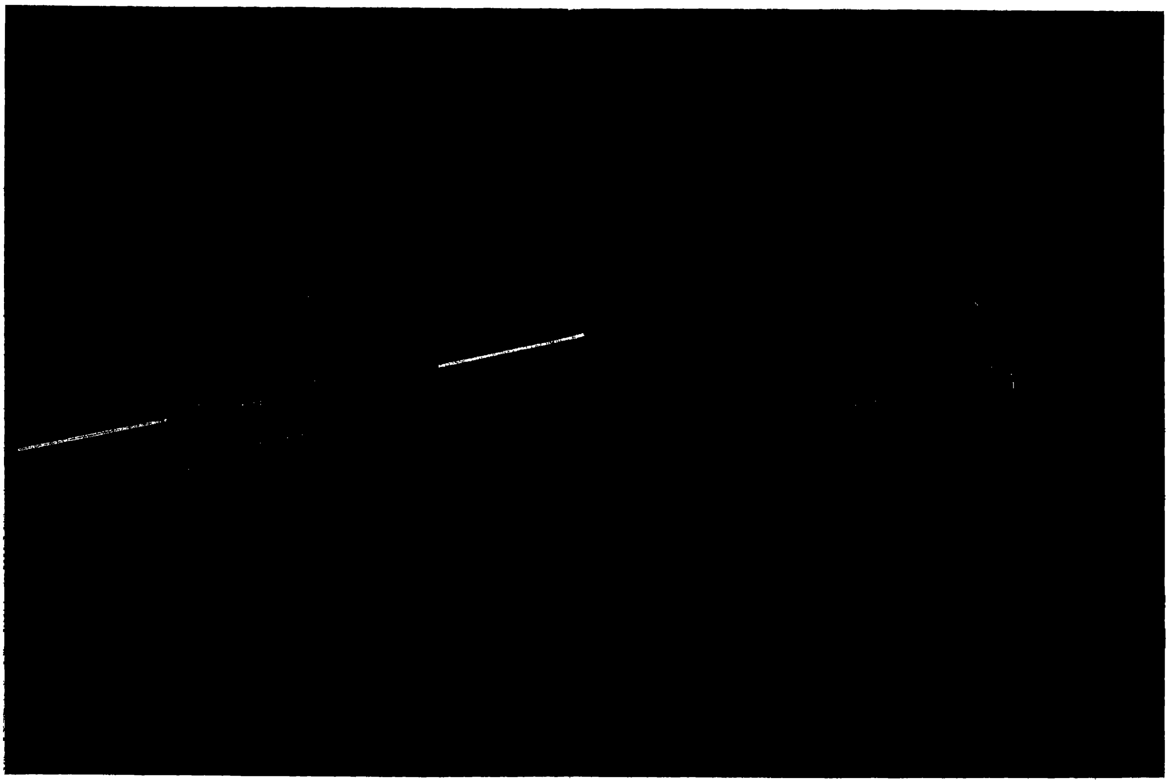
JUPITER AS SEEN FROM ONE OF ITS MOONS

This drawing is an attempt to depict Jupiter as it would be seen from one of its more distant satellites and is of course imaginary. The white circle on the right may be taken to be Satellite III which owing to its comparative proximity would appear larger relatively to Jupiter than as seen from the earth. The round black spot near it is its shadow. We may suppose the large grey spot further to the left to be Satellite IV which in consequence of its low albedo usually appears very dark when seen against the bright background of the planet's surface. The artist has suggested an atmosphere surrounding it but it is doubtful whether one of any appreciable density exists. (See Chapter VIII.)

the times when the plane of the ring passes through the Earth and the ring is therefore seen edgeways, there is an interval, usually of some weeks, before the plane passes between the Earth and the Sun (The passages of the plane through Earth and Sun are not simultaneous owing to the fact that the orbit plane of Saturn is slightly inclined to that of the Earth) When this happens, one face of the ring is illuminated by the Sun while the other face is presented to the Earth At such times the ring does not become invisible, but can be dimly seen by sunlight which has penetrated through it, notwithstanding that the illumination is very oblique, so that the rays of sunlight illuminating the underside of the ring have penetrated through a depth of ring substance equal to twenty or thirty times the thickness of its cross section

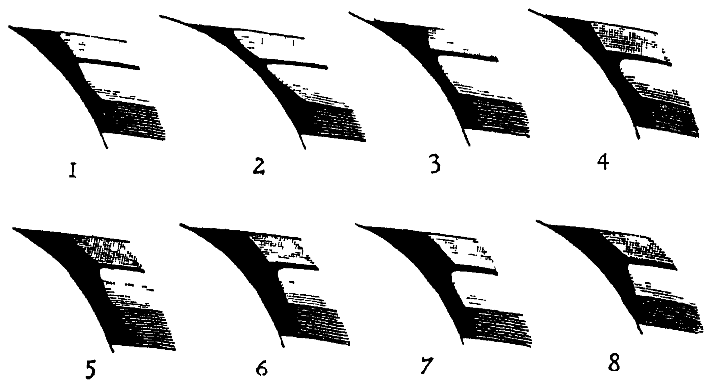
On several photographs of Saturn made in recent years the globe of the planet can be perceived through the outer ring This was first perceived in the photograph (taken in 1911 by the late Professor Barnard with the sixty-inch reflector at Mount Wilson) which figures as one of our illustrations, and of which the drawing on page 368 is an enlarged copy On two recent occasions when Saturn in his motion has "occulted" or passed in front of faint telescopic stars, such stars have been seen shining through the substance of the rings On the earlier occasion (February 9, 1917) the star escaped occultation by ring B, but was clearly seen shining through ring A On the second occasion (March 14, 1920) three observers watching the planet together, perceived the star to remain shining with comparatively little diminution of lustre, not only through ring A but through the densest part of ring B The fact is the more remarkable if we bear in mind that owing to the very oblique presentation of the ring at the date of the observation, the ray of light from the star had to pass through a depth of ring matter equal to about eight times the thickness of its cross section

A very remarkable fact about the ring is the high albedo or reflecting power of its brighter



TWO VIEWS OF SATURN

Saturn as viewed in a telescope of medium power about the time of the "disappearance" of the rings In the left hand drawing the illuminated surface of the rings is turned slightly towards the Earth, in the other the dark surface is turned towards the Earth and the ring is invisible In both views the shadow of the whole of the ring system can be seen



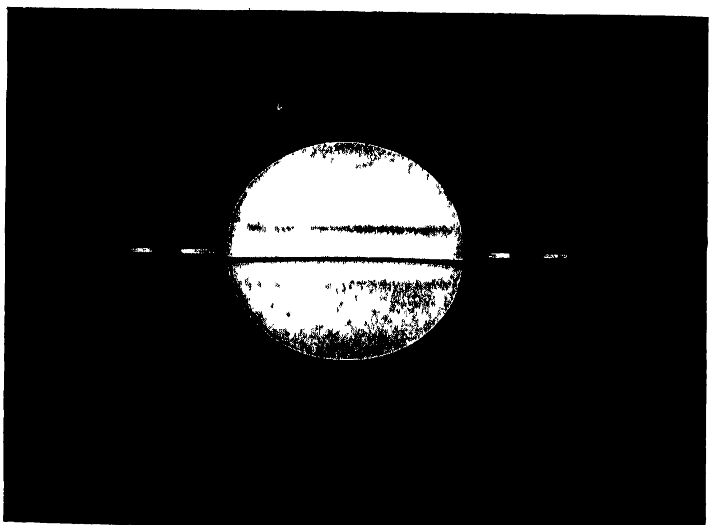
By permission of R. A. S.] [Elger

OUTLINE OF THE PLANET'S SHADOW ON RING

Portions of the three rings are shown where they pass behind the limb of the planet. The "peaks" in the shadow at the edge of the rings are illustrations of the optical phenomenon known as "the black drop." The narrowness of the shadow at the brightest parts of the rings is due to "irradiation." Probably all these phenomena are of the nature of optical illusions.

regions (see the discussion of albedo on pages 104, 107). We read in those pages that the average albedo of Saturn is very high. Naturally, the albedo of the brightest regions of Saturn is higher still. But the brightest regions of the ring are brighter than the brightest regions of Saturn. It is generally assumed that the rings are composed of meteoric matter, but whiteness such as this seems to the present writer to be inconsistent with this supposition. Such meteoric matter as comes our way is usually very dark in colour. Something dazzlingly white is required, and, though there are difficulties, the writer would suggest that the ring may perhaps be of analogous constitution to that of the high filmy clouds composed of minute ice crystals which we call cirrus or "Mare's Tails." We cannot, of course, think of such clouds as floating in an atmosphere, like our terrestrial clouds, but must suppose each separate minute particle to be pursuing an orbit in space round the planet like any ordinary satellite.

Viewing the ring as made up of myriads of small bodies pursuing their several orbits round Saturn, we may find a possible reason for the existence of Cassini's Division, and perhaps also for some of the other "divisions" already mentioned. The zone of asteroids lying between Jupiter and Mars has, as we have already been told, certain gaps which are devoid of these small planets. It was shown by Kirkwood that these gaps correspond to distances from the Sun at which a planet would have a period of revolution bearing a definite simple proportion to the period of Jupiter, for instance one-half of Jupiter's period, or two-thirds.



Drawing by] [W. H. Steavenson

SATURN NEAR THE DATE OF "DISAPPEARANCE" OF THE RINGS

Drawing made at the Greenwich twenty-eight-inch refractor on November 16, 1920, about nine days after the plane of the ring passed through the Earth. The unilluminated face of the ring is presented to the Earth and is seen faintly by sunlight penetrating through the ring. Dr. Steavenson says:—"It has been impossible to reproduce exactly the delicacy of the shadings in the rings; the contrasts are necessarily much exaggerated."

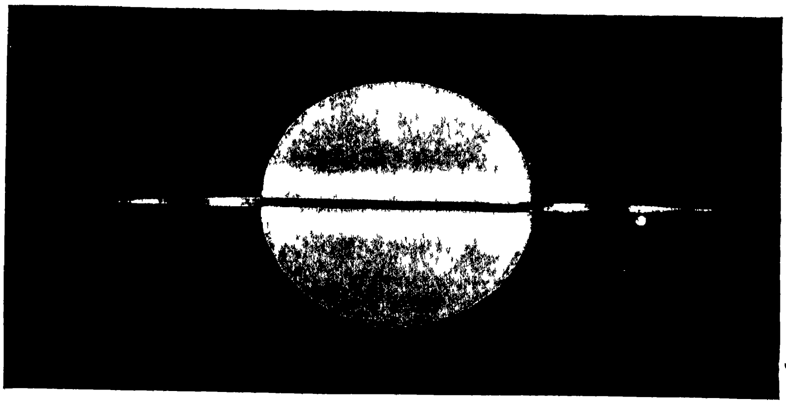
The idea is that planets whose periods bear such relations to that of Jupiter would at frequently recurring intervals in the same part of their orbit, be at their nearest points to Jupiter and so would get a constantly recurring push in one particular direction. The case is analogous to that of a swing. If we give a comparatively slight push to a swing at a particular point of its rhythmical "orbit" every time it gets to that point, we soon set up with very slight effort a very considerable alteration in the motion of the swing.

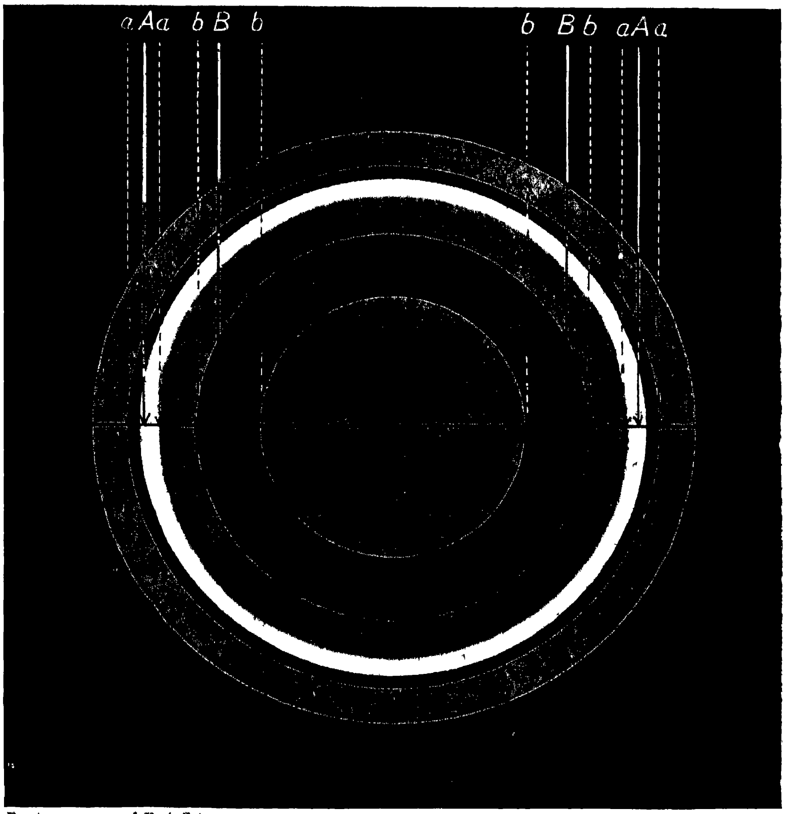
Now it is found that Cassini's Division is at a distance from Saturn

where the period of a particle would be exactly one-half that of Mimas and it happens also that relations of a similar character with the periods of certain of the other satellites, are also found near this distance

The theory is that any particle that happened to be in that place, or that managed somehow to get there, could not stay there but would be pushed either inwards or outwards There would result therefore a space which was continually being swept clear of particles The theory is attractive, but the problem of motion of bodies under such circumstances is exceedingly complicated and "Kirkwood's Law" as applied to the ring system of Saturn cannot be said to be definitely established as a complete or sufficient explanation of the phenomena Other dynamical hypotheses have recently been advanced to account for the same phenomena

If we look at any of the illustrations of Saturn, we shall see that the planet casts its shadow on the ring and some of them show the shadow cast by the ring on the planet These shadows greatly add to the beauty of the planet as seen in the telescope Since the Earth is never very far out of the line joining the Sun and Saturn, these shadows are, generally speaking, almost entirely hidden by the object casting them We are, however, usually in a position to see one edge or the other of the shadow of the ball on the ring, and it is so seen in all but one of our illustrations The outline of this shadow often shows curious irregularities, which have been considered by some to indicate that the surface of the rings is not flat It is probable, however, that these irregularities are not real and that they can be explained as optical effects due to the differences in brightness of the different regions of the ring and of the limb of the planet Even the photographic plate is not





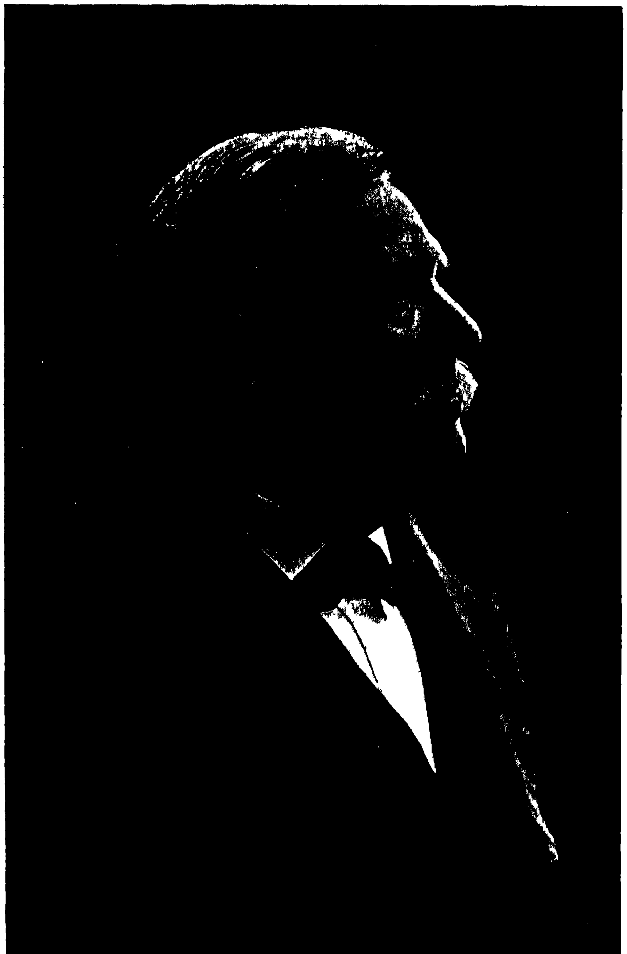
By permission of R A S] [*E E Barnard*

SATURN NEAR THE DATE OF "DISAPPEARANCE" OF THE RINGS

Drawing made at the Yerkes telescope November 25, 1907, the unilluminated face of the ring being presented to the Earth Two bright patches (seen also in Dr Steavenson's drawing) appear on each side of the planet The lower diagram shows that these patches correspond in position with the Cassini Division and the crape ring They are probably due to the bright illumination of particles lying in or near to these thin places in the ring system

immune from these illusive effects It will be noticed from a study of Professor Barnard's photograph and the drawing made from it that there seems to be a peaked shadow visible on both sides of the planet at once which is, of course, geometrically impossible This photographic effect is not difficult of explanation, and it is indeed quite analogous to the similar effect produced on the eye

With regard to the ring shadow, we would expect to see sometimes that of the outer edge of the system, and sometimes that of the inner edge As a matter of fact, it is as a rule only the former, the shadow of the outer edge of ring A, that we see That of the inner edge of ring B, when one might expect it to be visible, is confused with the trace of the crape ring across the planet The crape ring itself casts no perceptible shadow The fact that the shadow of ring A when visible appears black may be thought inconsistent with what has been stated about the diaphanous nature of the rings—but there is no doubt as to the latter fact, and the blackness of the shadow must be attributed to contrast At certain times near the " disappearance " of the rings, when they are seen edgewise, the shadow of the whole ring system can be seen clear of the ring itself, crossing the planet near its equator as a fine black line



By kind permission of] *[The " Observatory Magazine "*

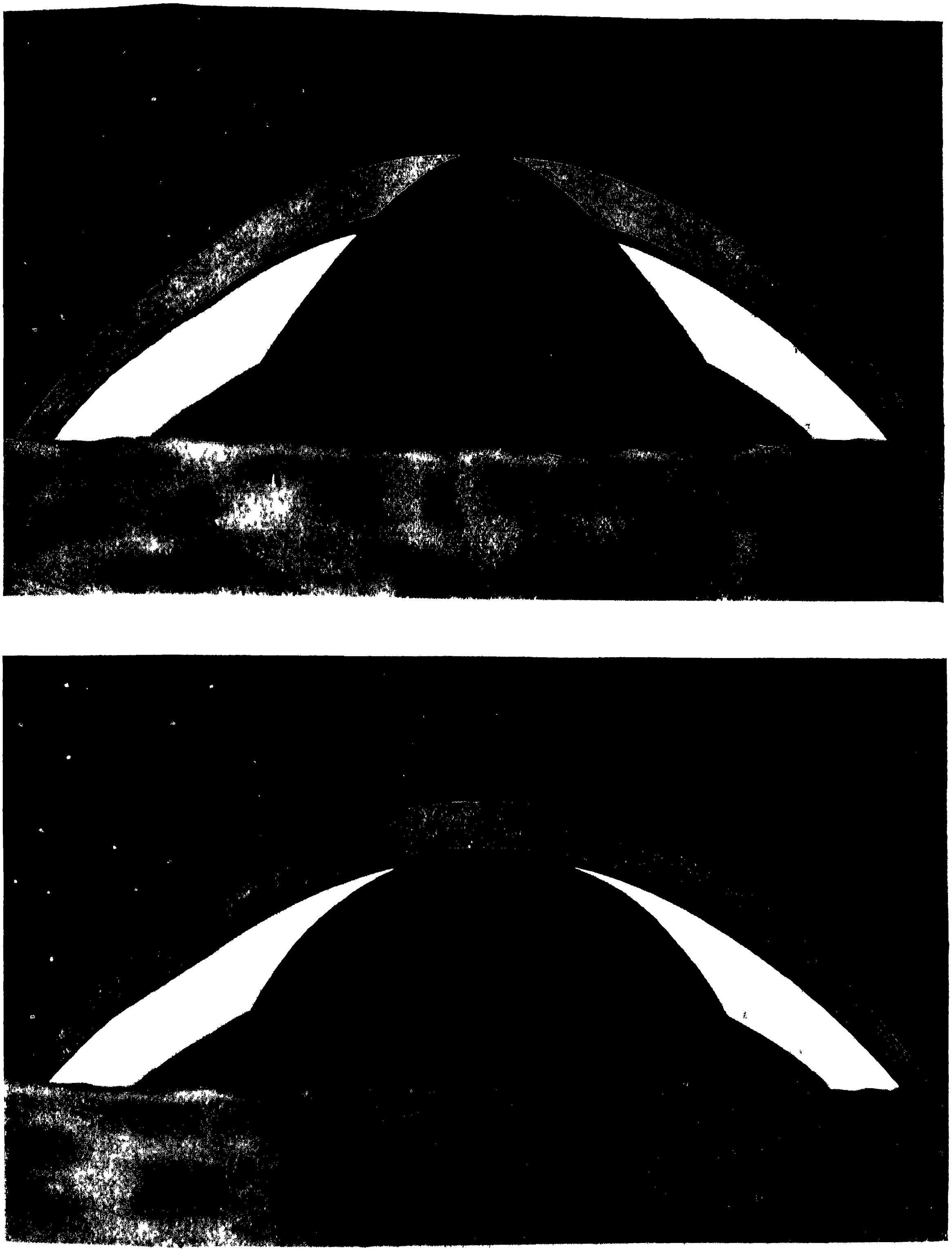
PROFESSOR E E BARNARD

A great planetary observer, besides having carried out magnificent practical work in other fields of astronomy His principal visual observations were made with the world's greatest refractors, the thirty six-inch at Lick and the forty inch at Yerkes Many of the illustrations of this work are copies of his photographs or drawings He died February 6, 1923

Over large regions of the planet the Sun suffers eclipse by the ring for months or even years at a time and some commiseration has been wasted on the non-existent inhabitants of the probably non-existent solid surface of Saturn who may be supposed to dwell in those regions Owing to the transparency of the rings, it seems, however, that the Sun would shine through the densest part of the system with but little diminution of light

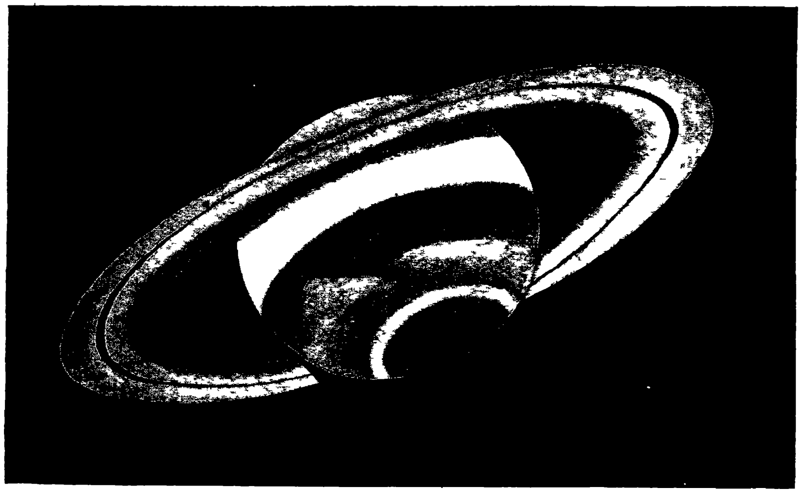
Why has Saturn a ring, alone among the heavenly bodies within reach of our telescopes ? Here is another question to which no answer in the least satisfactory has ever been given It was shown about the year 1848 by Roche, a French mathematical professor, that within a certain distance from any planet (which distance in the case of Saturn, corresponds pretty nearly to the outside circumference of the ring system) no considerable satellite can exist, because it must be disrupted by the strains to which it is subjected But this negative fact gets us no nearer to the answer to the positive question Why, in the case of Saturn, is the space that no satellite can occupy, filled by a ring ?

Perhaps the phenomenon may not be so rare as it seems to us After all, we only know of four bodies (Saturn included) which have physical characteristics in the least like those of the ringed planet Jupiter, Saturn, Uranus, and Neptune form a class by themselves for size, lightness of texture,

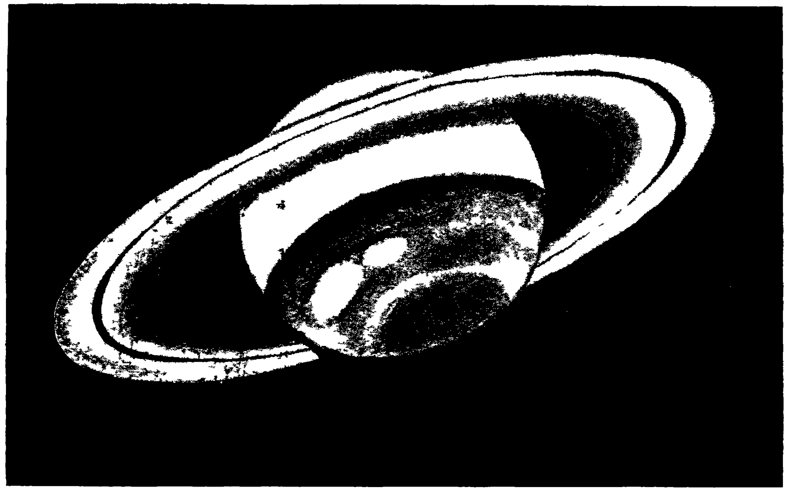


THE RING AS SEEN FROM SATURN

Two imaginary views of the rings as they would appear from the surface of Saturn, about midnight, at different seasons The upper drawing corresponds with the season shown on the bird's eye view (see page 375) The surface of Saturn is represented as a sea of clouds From large polar zones of Saturn no part of the ring system can ever be seen Probably, if we could transport ourselves to the view point of these sketches, the outlines of the ring would be nothing like so hard as they are here represented



1903, July 1, 14h. 45m



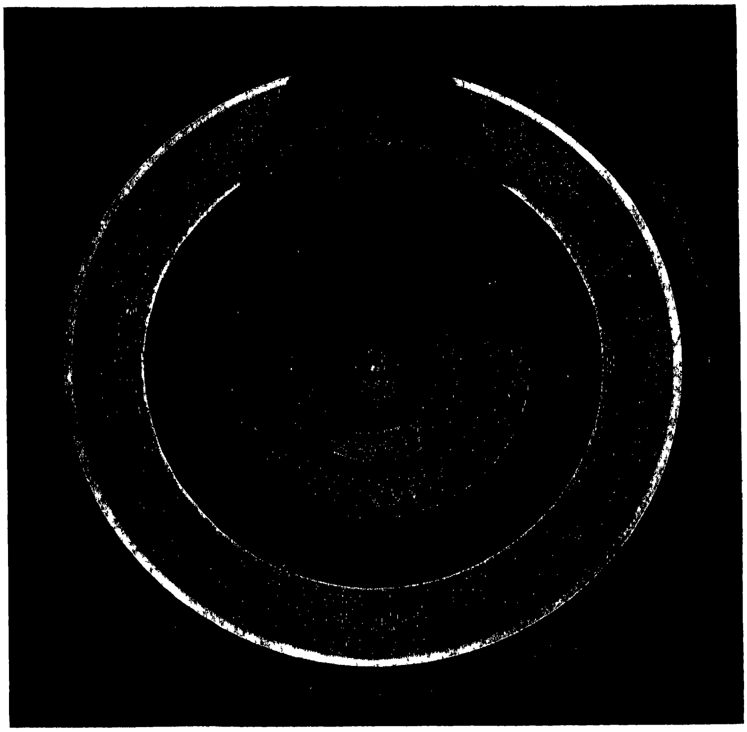
1903, July 12, 13h. 35m.

1903, July 9, 14h 4m

1903, July 16, 11h 52m.

These four fine drawings by Mr Denning illustrate one of the rare occasions when the planet has shown conspicuous spots They were discovered by Professor Barnard at Yerkes Observatory, and, a few days later independently by the author of these drawings at Bristol From his observations the author deduced a rotation period—confirmed by other observers—of 10 hours 38 4 minutes for the latitude of the spots (36° N) The equatorial rotation period is about 10 hours 14 minutes so that these spots show a westward drift compared with equatorial spots of nearly 900 miles per hour

and rapid rotation Compared with the other members of the Solar System they are swollen bladders The satellites of these planets, too, seem to be made of something different from earth stuff, they are abnormally white and abnormally light of substance Planets and satellites alike present seeming paradoxes—the ring that one of them has is hardly a greater paradox We can see millions of stars, hundreds of thousands of nebulæ, hundreds of small planets, but only four bodies like Saturn and, except in the possible case of an extra Neptunian planet, it does not seem very likely that we ever shall see any more One cannot but feel that a satisfactory physical theory that would account for the peculiarities of Saturn and his satellites and particularly for his ring would be a great step towards the understanding of the cosmogony and course of evolution of the Solar System



BIRD'S EYE VIEW OF SATURN AND RINGS
A view of the planet and ring system as seen from a point immediately over one of its poles The shadow of the planet on the ring is delineated as it would appear about a year before or after the summer solstice of the hemisphere shown, the ring as seen from the Earth being nearly at its maximum opening

CHAPTER IX

THE FRONTIERS OF THE SOLAR SYSTEM

BY REV T E R PHILLIPS, M A, F R A S

DOWN to the latter part of the Eighteenth Century Saturn was supposed to be the most distant of the planets, and, if we neglect the comets, its orbit marked the frontiers of the territory over which the Sun's sway was known to extend Strictly speaking we cannot thus treat the comets, as there is reason to suppose that they may, so far from being mere visitors who have come to us from more distant parts of space, be just as truly members of our Solar System as the planets They will, however, be dealt with in the following chapter, and we shall now limit our attention to the boundaries of the Sun's system of attendant planets

As above stated the ancients and, indeed, astronomers generally down to well within a century and a half ago, knew of no planet more distant than Saturn, which revolves round the Sun at a distance of about 886 million miles Indeed, the discovery of another planet outside the orbit of Saturn was so little anticipated that when a strange body was found by William Herschel in 1781, it was at first announced that he had discovered a new comet! When, however, it was demonstrated to be a planet, the discovery was naturally hailed as one of startling character and of prime importance It was in science what the discovery of America was in the affairs of the old world, indeed, it rather more than quadrupled the area covered by the Sun's planetary dominions regarded as a plane, and in recognition of the discovery Herschel received Knighthood and a pension from His Majesty King George the Third

Probably some of Herschel's other achievements are to be regarded as of even greater intrinsic importance than this one—we shall see later that he laid the foundations of various departments of astronomical research which in recent years have been astonishingly fruitful—but the discovery of a new planet was one which appealed in a unique way to men's imagination It was a thing without a parallel in historic times

It was on the night of March 13, 1781, when Herschel was making observations at Bath with a seven-inch reflecting telescope, that a suspicious looking object passed through the field of his telescope Any ordinary observer would have taken it for just a star and let it go, as had indeed been done several times in the case of this very object before, but not so Herschel! He was using at the time, he tells us, a magnifying power of 227 diameters, and he recognised at once that, whereas the "fixed" stars appear almost as points of light, this object had a perceptible disc After applying much higher powers and finding that its diameter appeared proportionately increased, he came to the conclusion that it could not be a star, and in the following words, taken from his statement which was communicated to the Royal Society, he announced his discovery of a supposed comet "On Tuesday, the 13th of March, between ten and eleven in the evening, while I was examining the small stars in the neighbourhood of H Geminorum, I perceived one that appeared visibly larger than the rest, being struck with its uncommon magnitude, I compared it to H Geminorum and the small star in the quartile between Auriga and Gemini, and finding it to be so much larger than either of them suspected it to be a comet"

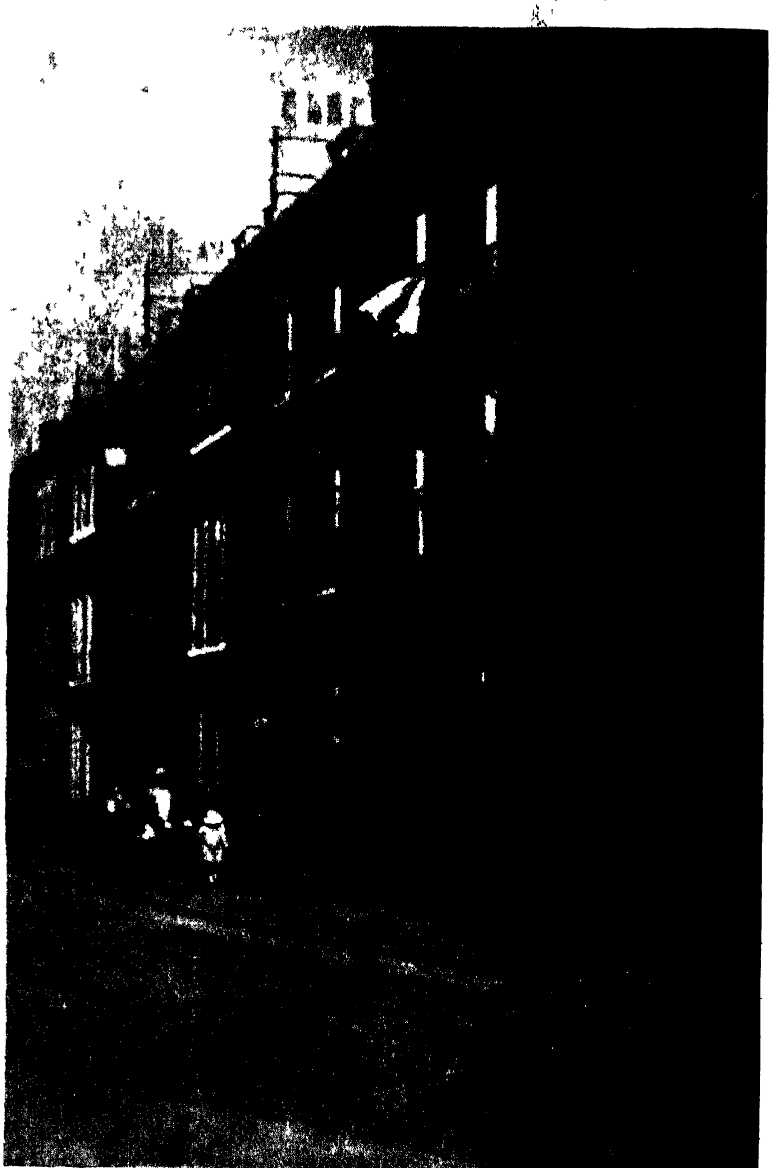


Photo by] [A P Baker, Bath

HERSCHEL'S HOUSE AT BATH

It was from the back garden of this house (the one with the flying curtains) that Herschel discovered Uranus with one of his home-made seven inch reflectors on March 13, 1781 A tablet commemorating the event can be seen affixed to the front of the house

So little, indeed, was such a thing as the discovery of a new planet anticipated, that some time elapsed before its real nature was even suspected, and several months passed before it was established that what Herschel had discovered was a hitherto unknown world revolv-

ing round the Sun outside the orbit of Saturn and at about twice the distance of that body. Naturally, Herschel felt that to him belonged the right of naming the new planet, and in a letter to Sir W. Banks, President of the Royal Society, he gave it the name "Georgium Sidus" (the Georgian Star) in honour of his royal patron. Some confusion followed. The French astronomer, Lalande, proposed the name Herschel, and this appellation was adopted for some years in France and even in England, while Bode, returning to classical usage, suggested the name Uranus—that of the oldest of the gods—as being most suitable. In the English Nautical Almanack the planet was styled *The Georgian* between 1791 and the edition for 1851, but from this date onwards the name Uranus has been in general use.

The mean distance of Uranus from the Sun is 1,782,800,000 miles, and a revolution in its orbit occupies eighty-four years. Its diameter is about 31,000 miles, and thanks partly to a high albedo, even exceeding that of Jupiter, it is just visible to unaided vision under favourable conditions, notwithstanding that it receives rather less than $\frac{1}{360}$ of the light falling on the Earth.

URANUS AND THE EARTH

The diameter of Uranus is nearly four times that of the Earth, or close on 31,000 miles. He is nineteen times as far from the Sun as the Earth is, so that he receives about 360 times less light. His surface, however, is highly reflective and this fact helps to make him just visible to the naked eye from the Earth. He takes eighty-four years to complete one circuit round the Sun.

In a powerful telescope Uranus appears as a sea-green, slightly flattened disc about four seconds of arc in diameter. Some observers have recorded the appearance of faint bands or belts, and especially a white streak across the centre. A curious circumstance, however, is that these bands have not always been drawn in the same direction; whereas if they are to be taken as indicating the direction of rotation, they should agree substantially with the plane of the orbits of the satellites. The markings are, however, very faint, and it is difficult to make certain of the precise details of features only just within the limit of vision. The density of the planet, deduced from the revolutions of the satellites and the diameter of Uranus, is very much the same as that of Jupiter, and the planet is probably in a somewhat similar physical state. The spectrum shows some heavy dark bands cutting out much of the red end, and to this is due the greenish colour of the disc. The absorption-bands may be taken as indicative of a somewhat dense atmosphere, but their exact identification is perhaps not quite certain.

Considering the practical difficulty in securing precise observation of an object like Uranus, we

Drawing by] [*W H Steavenson*

URANUS

Uranus appears as a very small disc even in a large telescope, so that little detail can be made out on his surface Faint markings, however, apparently resembling those of Jupiter and Saturn, have occasionally been seen The above drawing was made under good conditions with a ten-inch telescope, in September, 1915 It shows a broad white zone between two dusky belts

need not be surprised that there is still some uncertainty about its rotation period Some years ago the late Professor Lowell and Dr Slipher obtained by spectroscopic observations, based on the Doppler principle, the value of ten hours forty-five minutes Later, Mr Leon Campbell, at Harvard, in making photometric observations of Uranus for the purpose of finding whether or not any changes occurred in the Sun's light discovered variations in the light of Uranus in a period that agreed well with the result obtained by Lowell and Slipher Such light variations might easily be due to inequalities in the brightness of the planet's disc, caused, perhaps, by an outbreak of spots, combined with axial rotation, and it is probable that the results obtained are very nearly correct

The satellites are four in number, and bear the names Ariel, Umbriel, Titania, and Oberon, Ariel being the nearest to the planet Sir William Herschel discovered Oberon and Titania a few years after his discovery of Uranus Ariel and Umbriel were discovered by Lassell, in 1851 They are exceedingly small and faint But the most interesting point in connection with the satellites is the inclination of the plane in which they revolve Reckoned in the usual way, this is more than a right angle—actually 97° 8—so that projected on the plane of the ecliptic the motion is retrograde

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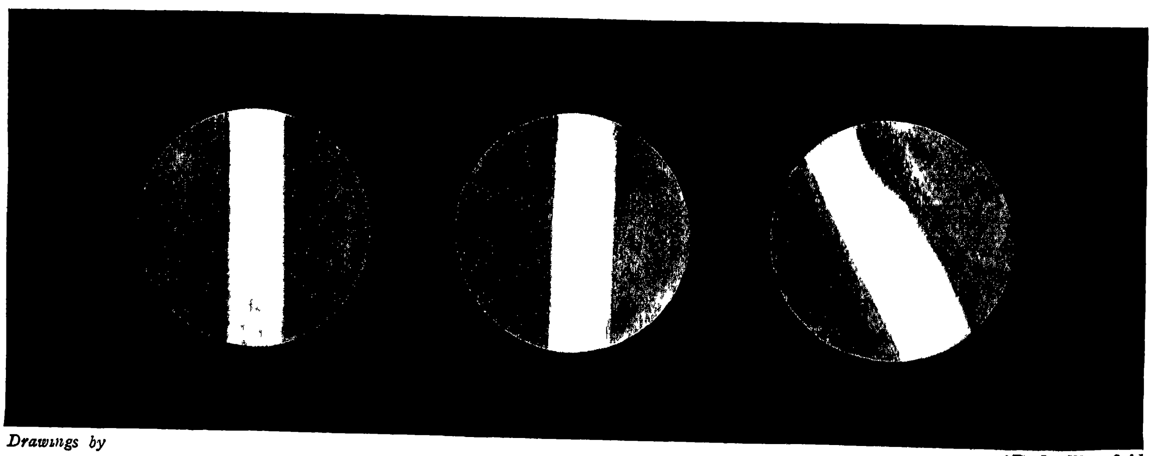


Drawings by [*R L Waterfield*

MARKINGS ON URANUS

The above drawings, made with a ten inch refractor and powers from 500 to 700, show how the bright central stripe, or zone, occasionally observed on Uranus, appears to change its position on the disc In the first two views (1915, September 6 and 7), it appeared to be parallel in direction to the plane of the satellite orbits, but in the third (1916, September 9) it seemed to be inclined to them as much as twenty five to thirty degrees

As already stated, the area known to be covered by the planetary system was greatly extended by William Herschel's discovery of Uranus, but we now have to consider the remarkable and thrilling story of a yet further extension of the boundaries of that system. In many respects the discovery to be recounted was of a totally different character from that of Uranus. It depended primarily, not on the acute vision of a skilful observer—indeed, the part played in it by the telescope was entirely a subordinate one—nor did chance or good fortune have very much to do with it except, perhaps, in the final stages, but it was more than anything else a triumph of mathematical reasoning.

It has been already stated that, before Uranus travelled across the field of Herschel's telescope and was at once recognised by him as something different from a star, it had been observed and recorded, without, however, anything unusual being noted. Nearly a century earlier, viz., in 1690, as well as in 1712 and 1715, Flamsteed, the first Astronomer Royal, had observed it and determined its position. Later, it was observed by Le Monnier, Bradley and Mayer—all of them good observers. These men had, accordingly, had the opportunity of making a startling discovery. The prize had

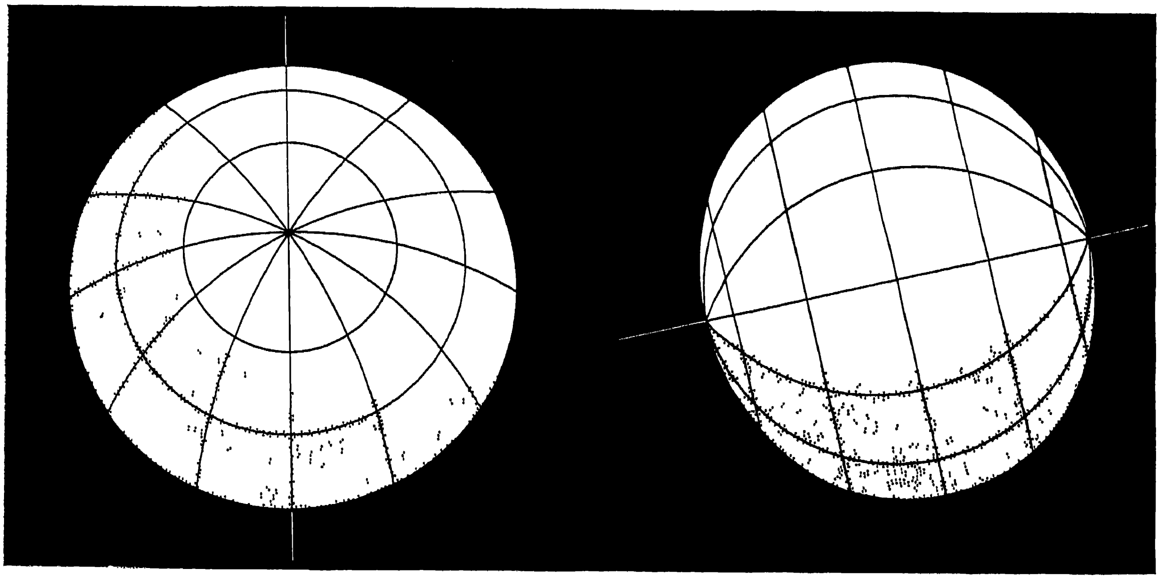


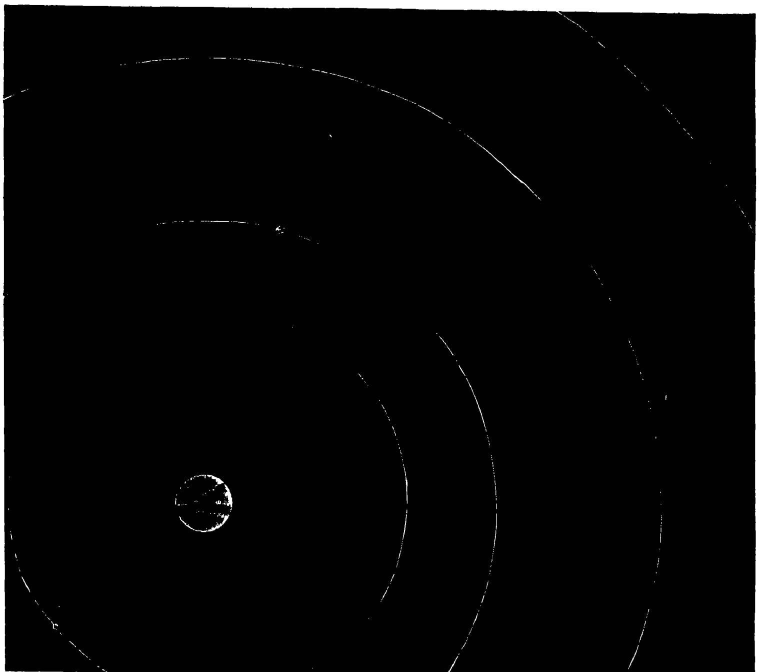
FIGURE OF THE GLOBE OF URANUS

Uranus, like Jupiter and Saturn, is appreciably flattened at its poles and is an oblate spheroid. This is due to rapid rotation on his axis, the period of which is about ten and three-quarter hours. This flattening of the poles is not always visible from the Earth. Thus, in the first of the figures above, the planet's axis is pointing nearly towards us, and his outline consequently appears all but circular.

actually been within their hands, but they had let it go; they had missed their chance, and it was reserved for the acuteness of Herschel to gather what they had lost!

But the older determinations of position were of value nevertheless. When the planetary nature of the new object was established it was at once recognised that they should enable the "elements" of its orbit to be derived with great accuracy. It is obviously easier to find the dimensions of a circle from a large arc of its circumference than from a very small one, and similarly it was felt that the arc of the orbit of Uranus traversed since Flamsteed's first observation ought to give the elements of its elliptical path with great exactness. The orbit was accordingly worked out with much care, but it was found impossible to fit all the observations with the degree of accuracy expected. And however the elements were varied so as to make the discrepancies between theory and observation as small as possible, the planet soon began to wander away from the track predicted for it. As a matter of fact, so hopeless did the problem gradually become that when drawing up fresh tables in 1820 Alexis Bouvard discarded the older observations altogether, and based his computations solely on observations of the planet's position obtained since its discovery by Herschel. As we now know,

the discrepancies were by no means wholly due to inaccuracies in the old observations and it was soon found that the planet was wandering away even from the new path that was laid down for it It is true that the errors, as judged by ordinary standards, were small, indeed, such as would be quite imperceptible to the naked eye even after the lapse of some years, but by 1844 the discrepancy had increased to two minutes of arc, *i e*, about one-sixteenth of the Moon's apparent diameter, or about two and a half times the diameter of Jupiter at opposition—an error much in excess of anything that might have been expected Of course, every allowance was made for the disturbing effect of the other planets, especially Jupiter and Saturn As already explained in earlier chapters, the various bodies of the Solar System, in accordance with Newton's Law of Gravitation, mutually perturb one another, and some of these perturbations are considerable After, however, making full allowance for all such known effects, the outstanding discrepancies referred to still remained to be accounted for, and the idea gradually took shape that they might be explained on the hypothesis of some as yet unknown planet, still more distant than Uranus, disturbing the motion of the latter



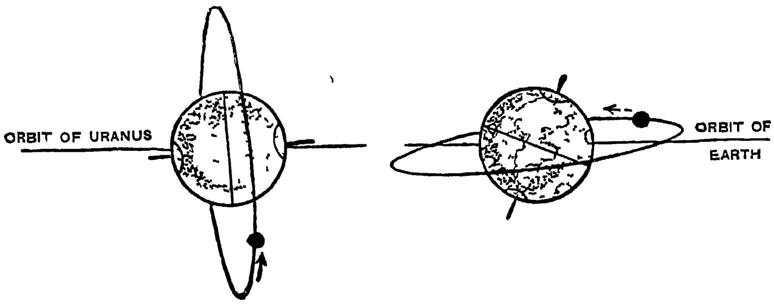
From "Astronomy for All"] [*By permission of Messrs Cassell & Co, Ltd*

THE SATELLITES OF URANUS

Uranus is attended by at least four satellites, and more have been suspected The four definitely known are, from the planet outwards, named Ariel, Umbriel, Titania, and Oberon They are among the faintest objects known to us in the Solar System and require a very large telescope for their successful observation They appear as mere points of light at such an enormous distance

The inverse problem of finding the disturbing body from the observed perturbations was a difficult one It required mathematical skill of a high order as well as an accurate series of observations for its solution The latter were fortunately available, and shortly before the middle of the last century two young men, quite independently and quite unknown to each other, resolved to attack the problem

One of these was J C Adams, of St John's College, Cambridge, and it is recorded in a memorandum left by him that in the summer of 1841 he "formed a design to investigate, as soon as he had taken his degree, the irregularities in the motion of Uranus which were as yet unaccounted for in order to find whether they might be attributed to the action of an undiscovered planet beyond it, and, if possible, thence to determine the elements of its orbit, etc, approximately, which would probably lead to its discovery" This resolve Adams carried out His first solution was obtained in the long vacation of 1843, and several others followed, so earnestly and enthusiastically did he labour at the problem he had taken up In September, 1845, at the instigation of Professor Challis, of Cambridge, he called at the Royal Observatory, Greenwich, to see Airy, the Astronomer Royal Unfortunately, Airy was not at home He called again a few weeks later, and once more missed seeing him This time, it seems, Airy was at home but at dinner, and the butler, unwilling that his master should be disturbed, sent Adams away The latter did, however, leave a paper containing the elements he had derived for the supposed disturbing planet outside Uranus, and other details This communication Airy acknowledged by letter and at the same time asked a question which



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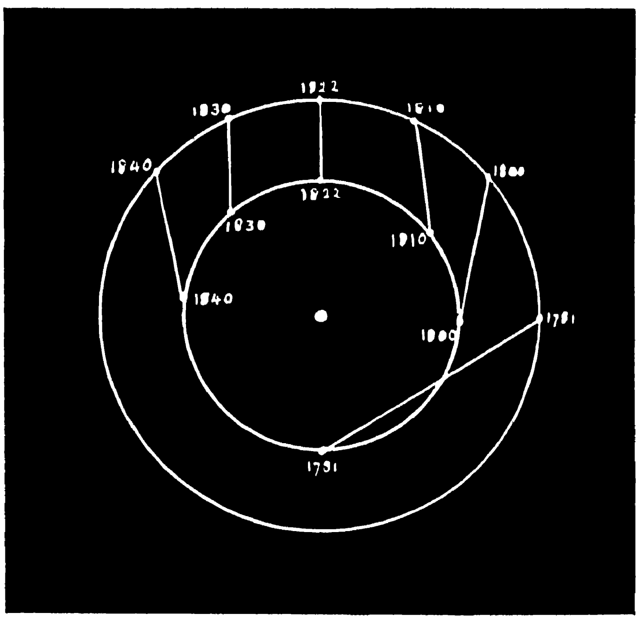
AXES OF URANUS AND THE EARTH

Uranus travels round the Sun with his axis of rotation lying almost in the plane of his orbit. In the case of the Earth the two make an angle of sixty-seven-and-a-half degrees. The figure above shows also (but not to scale) the relation of the satellite orbits to the axes of the two planets. In the case of Uranus the tilt of the axis is so excessive (more than ninety degrees) that the satellites appear to revolve in the retrograde direction

he then considered a crucial one, viz., whether the assumed perturbation would explain the considerable error in the *radius vector* of Uranus. Unfortunately, Adams made no reply to this question. He was naturally of a shy and diffident disposition, he was disappointed at his failures to see Airy, and probably, too, at what he may well have considered the latter's lack of confidence in him, if not indifference to the results he had obtained. Indeed, the answer to the question seemed to Adams so obvious that he perhaps thought Airy was merely trying to evade the matter altogether. Anyhow he sent no reply, and Airy for the time being took no further action in regard to the problem.

Meanwhile, the unexplained irregularities in the motion of Uranus had attracted the attention of the young French astronomer and mathematician, U. J. J. Le Verrier, who in the summer of 1846 communicated three important papers to the French Academy dealing with the problem, and in the last of these he expressed his belief that the planet could be recognised by its disc. On seeing his preliminary figures Airy was so struck by the general resemblance which they bore to those deduced earlier by Adams that he considered the time had arrived when a diligent telescopic search should be made for the disturbing planet. As an illustration of the growing interest in the problem, it may be mentioned that on September 10 of the same year, at the meeting of the British Association, held at Southampton, Sir John Herschel remarked: "We see it (*i.e.*, the planet) as Columbus saw America from the shores of Spain. Its movements have been felt trembling along the far-reaching line of our analysis with a certainty hardly inferior to that of ocular demonstration." How near at hand that ocular demonstration was the sequel shows. But to return to our story. Airy supposed that a large telescope would be required to reveal the planet, and in the belief that there was no instrument at Greenwich adequate for the purpose, he asked Challis to search for it with the Northumberland telescope at Cambridge, of which the object glass has a diameter of eleven and a half inches. Challis agreed to do so, but as he had no chart of that part of the sky available he adopted the slow and laborious method of determining carefully the positions of the stars in that region down to the tenth or eleventh magnitude, and repeating the observations again and again



THE "PULL" OF NEPTUNE ON URANUS

The observed fact that Uranus appeared to be accelerated in his orbit up to 1822 and thereafter retarded led to the deduction that the gravitational "pull" of an exterior planet was responsible. The diagram represents the relative positions of the two planets at different times, as calculated backward after the actual discovery of the disturbing planet, Neptune

in the knowledge that if the planet were in the field it would betray itself by its motion

While Challis was thus engaged, Le Verrier sent his final results to Dr Galle, at Berlin, who on September 23, 1846, received his letter requesting him to direct his telescope to a point on the ecliptic in the Constellation Aquarius in about longitude 326°, where he might expect to find the new planet It so happened that Galle had ready to hand a map by Bremiker of that region of the sky, and that very evening a comparison of the stars in the sky with the stars on the map revealed the looked-for stranger !

It thus happened that the credit for the discovery of the new planet went to Le Verrier and Galle, notwithstanding the fact that Adams was the first to carry through the mathematical part of the work The circumstances were such, however, as naturally to provide the occasion for controversy, and much heated argument ensued On the one hand, there were those partisans of Le Verrier who were greatly annoyed when claims were put forward on behalf of Adams, and on the other, some of the supporters of Adams could scarcely find language strong enough to express their feelings about Airy and Challis, especially the former As a matter of fact, if Challis had only compared the observations he had already made in the first half of August the prize would have been won for English Astronomy, for twice—on August 4 and again on August 12—he had observed and recorded the position of the object, and its motion between the two dates, had he noticed it, would have disclosed to him its planetary nature !

By permission of] *[Messrs Macmillan & Co*

JOHN COUCH ADAMS

A portrait, taken in later life, of the young Cambridge mathematician who, working on the perturbations of Uranus, anticipated Le Verrier in arriving at a solution of the problem Unfortunately, a combination of circumstances delayed the verification of his result, which was afterwards shown to be very near the truth

From "Astronomy for All "] *[By permission of Messrs Cassell & Co, Ltd*

U J J LE VERRIER

Working in complete independence Le Verrier arrived at a result almost identical with that already reached by Adams It was the news that the great French mathematician was working at the same problem that caused, too late, a revival of interest in the work of Adams and a desire to verify his results

Looking back on this remarkable story from a distance it is easier, perhaps, for us to form a just judgment on the events of that time than was possible for those immediately interested in them No doubt Airy can hardly be regarded as wholly free from blame He might have been expected, despite the many and constant calls on the time of one holding his position, to have shown more sympathetic interest in the work of Adams, and it seems certain that his seeming coldness caused Adams to refrain from further communication with him Challis has been greatly blamed for incompetency It has been pointed out that he should have been able to deal with the matter himself without sending Adams to Airy at all

But Adams himself made a mistake He apparently suffered from too sensitive and retiring a nature, and he ought certainly to have replied to the Astronomer Royal's question about the error of the radius vector Indeed, it is only fair to mention here that after the appearance of his first paper to the French Academy, Airy had put the same question to Le Verrier who sent him a reply during the next few days

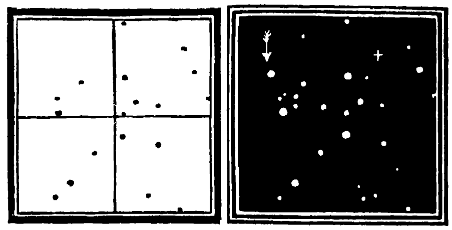
Of course, the failure of Challis to compare his August observations was a misfortune that was quite in keeping with Adams's inability earlier to get into touch with Airy on the occasions when he called on him at Greenwich It was, then, as the result of many contributory causes that England in general and Cambridge in particular lost the technical honour associated with the discovery of the new planet On the other hand, Le Verrier was able to carry through his work to its final conclusion without any of the difficulties and obstacles which hindered Adams Perhaps we may go so far as to say that it was a piece of great good luck that when Le Verrier's letter arrived Galle had a map of the particular region of the sky indicated and, further, that the planet should have been just within that area Actually, it was situated in a part of the sky which came in the lower left-hand corner of the map It might so easily have been outside it altogether!

JOHANN GOTTFRIED GALLE
Galle was the first astronomer to observe Neptune with the knowledge that it was a planet The probable position of the latter was given by Le Verrier, and Galle, aided by a large telescope and a good star-chart, was able to identify the planet on the very first night of his search

It is, perhaps, needless to say that the two great men specially concerned took no part in the heated controversy that was aroused We can imagine that Adams's disappointment at the untoward course of events must have been very great, but he always spoke in the warmest terms of the great ability and wonderful achievements of Le Verrier After all, really great men may well be indifferent to the measure of praise and honour accorded them, since the thing that really matters in the history of man's progress is that discoveries should be made, by whom they are made is a matter of secondary importance, and, moreover, though mutual jealousies and the purely personal element in scientific work may sometimes distort contemporary judgment, the verdict of posterity is apt to be sound, and in this case the scientific world now accords equal honour to the brilliant Frenchman and the equally deserving, though less fortunate, Englishman, who independently accomplished so magnificent a piece of work

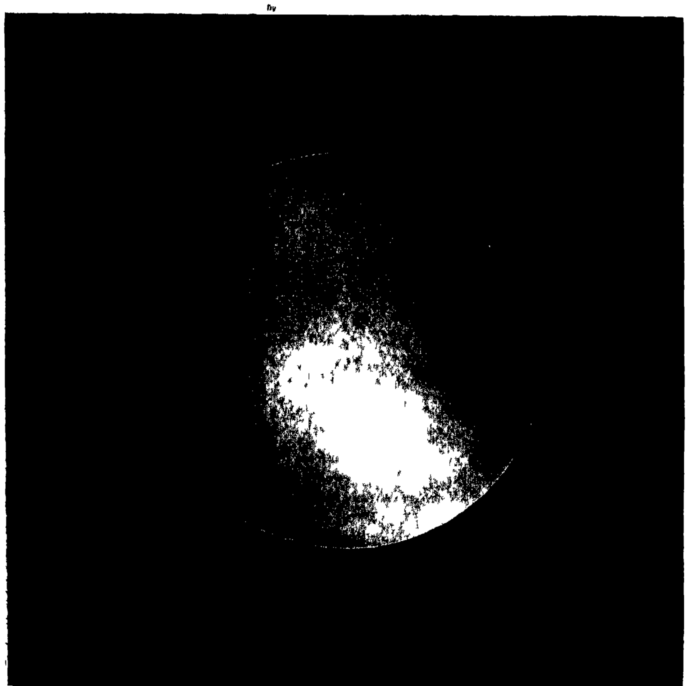
In concluding this sketch of a very striking episode in the history of Astronomy it is only fair to point out that the actual orbit of the new planet—now known as Neptune—is very different from that assigned to it by either Le Verrier or Adams Of course, some assumptions had to be made in work of this sort, and both investigators assumed the distance of the disturbing body to be about twice that of Uranus from the Sun, as suggested by Bode's law As it happens, this assumption, which was a perfectly natural and justifiable one in the face of known facts, led them astray The value given for the distance of Neptune by Bode's law is nearly thirty-nine times the distance of

the Earth from the Sun, whereas the actual distance is only thirty times There were, accordingly, those who went so far as to assert that the real orbit being so different from the computed ones, the planet that was found was not the plane of Adams and Le Verrier at all, and that its discovery was due to a mere coincidence or happy chance It is, however, generally agreed that this view of the matter is not quite fair, since the perturbations in the portion of the orbit traversed since 1690, when the planet was first observed by Flamsteed, though obviously not capable of furnishing correct elements on the primary assumption of Adams and Le Verrier, were nevertheless of such a nature as to indicate the direction in which the disturbing body should be looked for The late Professor Lowell has attributed the successful result achieved to the *nearness* of Neptune and the approximate *circularity* of its orbit, and adds " Neptune turns out to have been most complaisant and to have assisted materially to its own detection "



NEPTUNE IDENTIFIED
To the left is a reduced copy of part of the chart used by Galle in his search for Neptune To the right is the same portion of the sky as he actually found it, with Neptune present as a " stranger " to the region The small white cross to the right marks the place predicted by Le Verrier, less than a degree away

Of Neptune itself comparatively little is known Its mean distance from the Sun is 2,793,500,000 miles, and the time required for a revolution in its orbit about 164 8 years Its diameter, according to Barnard, is about 33,000 miles, so that it appears to be slightly larger than Uranus Owing to its distance no definite markings are visible on its surface It presents in the telescope a greenish disc, about 2 6 seconds of arc in diameter, and being no brighter than a star of the eighth magnitude, is much too faint to be visible to the naked eye As regards its physical condition, Neptune probably bears some resemblance to the other large planets, Jupiter, Saturn, and Uranus From the periodic time of its satellite taken in conjunction with the planet's dimensions we learn that its density is low, viz , about the same as that of Jupiter There are some very strong absorption bands in the lower part of its spectrum, similar to but broader than those of Uranus Progressive changes in some of the lines and in one broad band in the spectra of Jupiter, Saturn, Uranus, and Neptune are shown in the photograph on page 386 The rotation period of Neptune is still uncertain , but in 1883 and again in 1915 Maxwell Hall deduced the values seven hours fifty-five minutes and seven hours fifty minutes six seconds respectively from observations of temporary variations in the light of the planet as compared with that of stars in the same fields If these results are correct, it is the shortest known rotation period in the Solar System, but the speed of a point on the planet's equator will be only about 220 miles per minute as compared with 470 miles per minute in the case of the



Drawing by] [*W H Steavenson*

NEPTUNE, 1916
Very little has been seen on Neptune's disc, which is faint and minute in all but the largest telescopes Like Uranus, the planet is greenish in colour Suspicions of belts, and dusky shadings at the limbs, have been obtained and a flattening of the polar diameter has been measured The rotation period is still in doubt, but is probably of the order of eight to twelve hours, and thus comparable to those of Uranus, Saturn, and Jupiter

giant planet Jupiter So far as is known, Neptune has but one moon It was discovered by Lassell within a month of the discovery of Neptune by Galle Like the outer satellite of Saturn, the eighth and ninth of Jupiter, and the four of Uranus, it has a retrograde motion The inclination of its orbit to the plane of the ecliptic is 145° 1 or 34° 9 It has been named Triton, but is more often referred to simply as the "satellite of Neptune"

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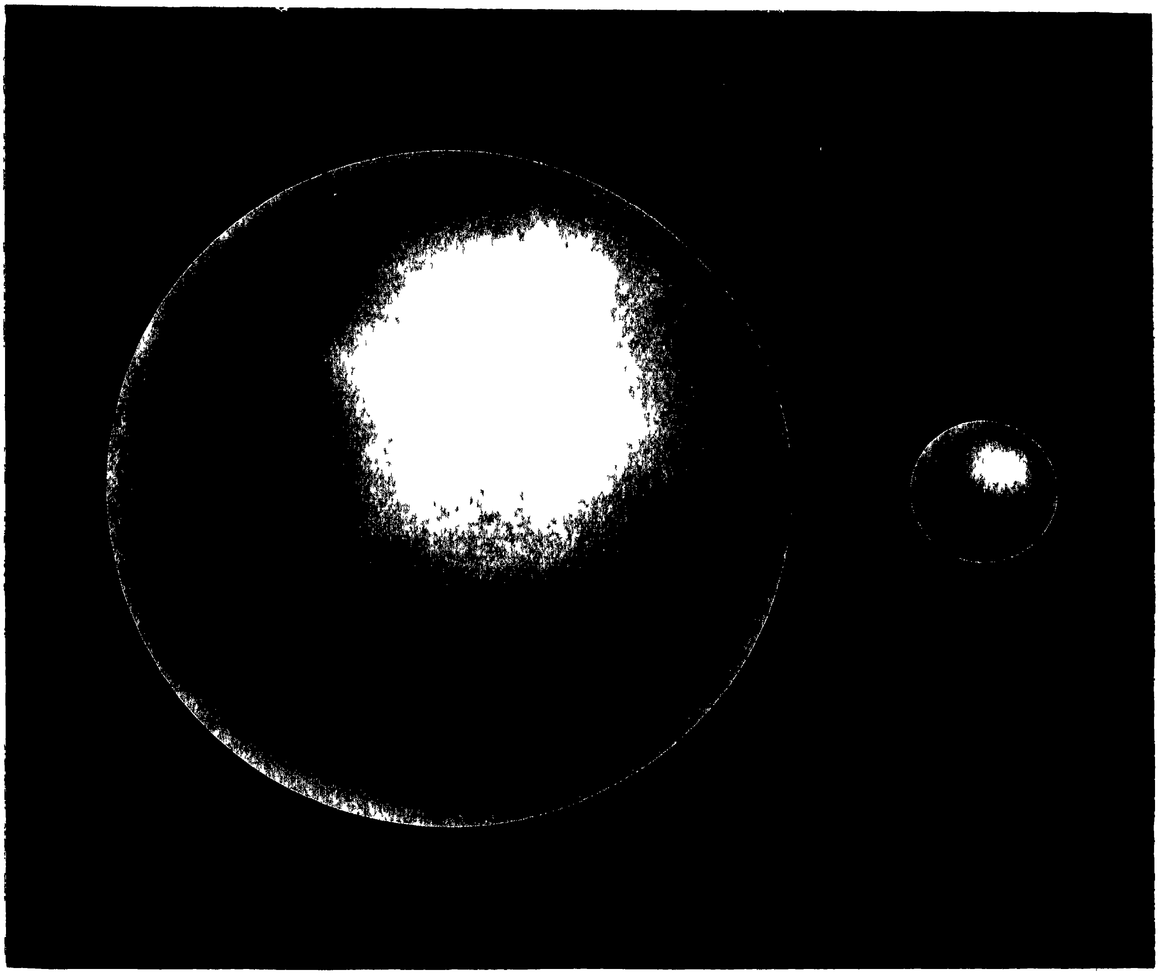
Is Neptune really the frontier planet of our system, or are there others still more remote? At



NEPTUNE AND THE EARTH

Neptune and Uranus form a pair of apparently similar planets The former is slightly the larger of the two, being about 33,000 miles in diameter, or four-and-one-fifth times the diameter of the Earth The diagram above makes Neptune rather too large Owing to his great distance from the Sun (thirty times that of the Earth) he appears as a very dim object, only visible in a telescope. He takes nearly 165 years to revolve round the Sun

present the question does not admit of a definite answer We have already seen that Bode's law breaks down at Neptune Does this mean that there is no other planet beyond it? The problem has naturally received the attention of several astronomers, and it has been approached from more than one direction In the chapter on Jupiter, and in the chapter to follow, on Comets, reference will be found to the fact that in the cases of comets known to return to the neighbourhood of the Sun periodically, their aphelia (*i e*, the most distant points in their orbits) lie close to the orbits of the larger planets Thus Jupiter has associated with him a family of about fifty comets, Saturn has three, Uranus two, and Neptune seven It is reasonable, therefore, to conclude that the existence of a

trans-Neptunian planet might be revealed by the discovery of a family of comets whose aphelia lie outside Neptune's orbit From an investigation based on these lines, Professor George Forbes, in the year 1880, concluded that such a planet actually exists, and a subsequent rediscussion of the problem, with additional data, enabled him (in a paper communicated to the Royal Astronomical Society in December, 1908) to confirm substantially his earlier results He was led to the conclusion that the new planet is about 105 times as distant from the Sun as the Earth, or three and a half times as remote as Neptune, with a period of nearly 1,100 years The orbit plane of this hypothetical planet, however, is inclined to the ecliptic, at an extraordinarily high angle, viz , 52°, which is altogether different from those of the major planets, and exceeds by some 18° even that of the minor planet

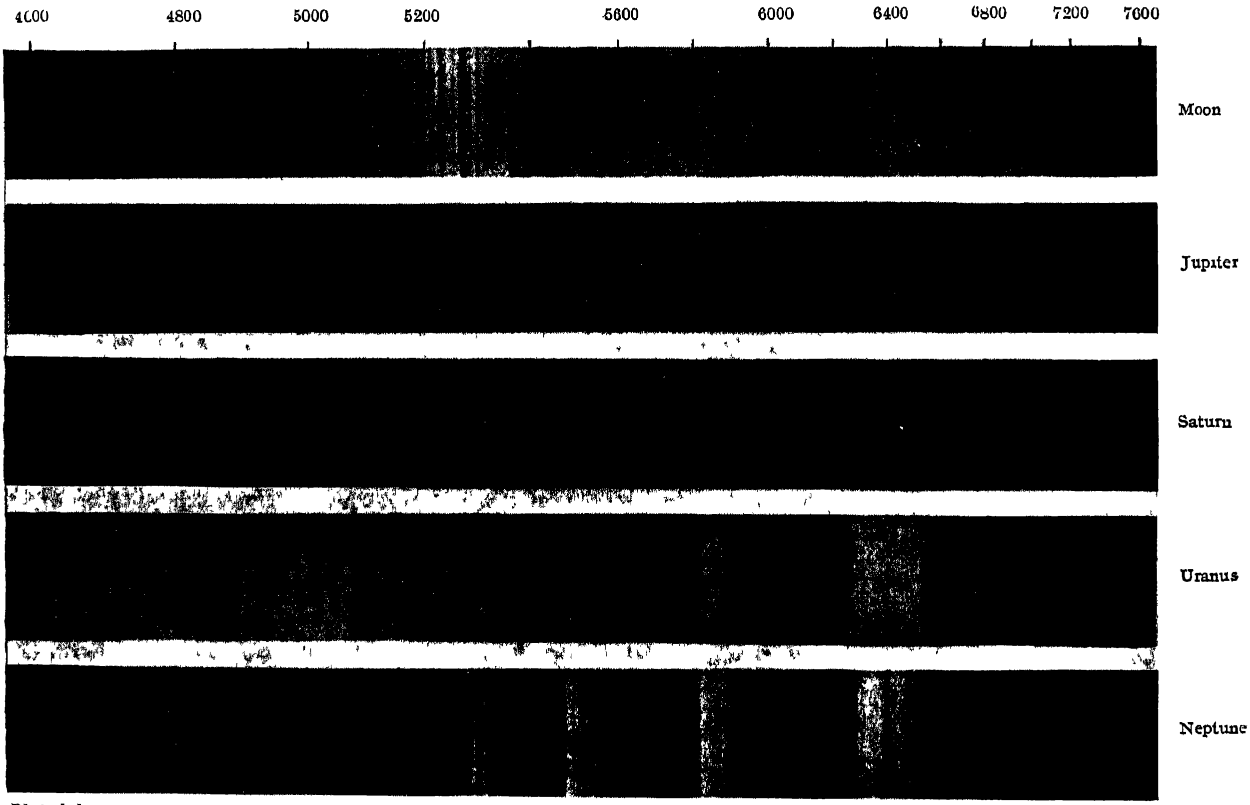


Photo by] [*Lowell Observatory*

SPECTRA OF THE GIANT PLANETS

The spectra of all the planets are similar to that of the Sun, from which they derive their light, but in the case of Jupiter, Saturn, Uranus, and Neptune (especially the last two) there are found, in addition to the fine lines, several broad dark bands These must be due to absorption by gases in the atmospheres of these planets, which have not been identified with certainty

Pallas ! But perhaps a high inclination in the case of a planet so remote is not utterly improbable The orbits of comets which come from a great distance and are possibly composed of outlying portions of the original nebula of the Solar System, which may well have been spherical, may have any inclination, so that a high inclination of the orbit of an exceedingly remote planet is not necessarily at variance with what might have been expected

But most of those who have attacked the problem of a trans-Neptunian planet have based their investigations on the perturbations of the orbit of Uranus It may be asked why not make use of the perturbations of the orbit of Neptune ? Obviously, these would be larger in amount, and would therefore yield more trustworthy results, but unfortunately Neptune has not yet been observed over a sufficiently large arc of its orbit to render the perturbations certain Computers have

accordingly been obliged to fall back upon the residual perturbations of Uranus, after the disturbing effects of Neptune—in addition to those of the other planets—have been subtracted. This is something like trying to find Neptune from the disturbances produced by it in the orbit of Saturn, and the quantities available for discussion are exceedingly small. According to the late Dr Percival Lowell, who in 1915 published a detailed investigation of the problem based on these lines, the residual disturbances at no point exceeded 4.5 seconds of arc, as against 133 seconds which Adams and Le Verrier had to deal with in 1845! Nevertheless, he deduced from them consistent evidence suggesting a planet moving in an orbit with a radius of about forty-five times that of the Earth's. He assigned to it a mass of the order of one fifty-thousandth part of the Sun's mass, and predicted an apparent disc of over one second of arc in diameter. Amongst others who have discussed this interesting problem are Todd, Lau Lee, W. H. Pickering, and Gaillot, and between some of the results which have been deduced there is a fair agreement. So far, however, all attempts to discover the supposed planet in the heavens have failed. No doubt, in the course of time, when the interval since Neptune's discovery has become sufficiently great, its own orbit will be studied for evidence of the perturbing action of a possible planet yet more remote; but meanwhile, despite the investigations referred to, the frontiers of the planetary system as known remain undisturbed. It is, of course, quite likely that the Solar System in its entirety, *i.e.*, including any trans-Neptunian planets which remain to be discovered, and the comets, has a diameter which exceeds many times that of Neptune's orbit, and yet the distance of its remotest parts is small compared with that separating the Sun from its nearest neighbours amongst the stars. Indeed, so great is this intervening space that the solar beams, though travelling with a speed of over 186,000 miles per second, require years to traverse it. How these distances are determined will be explained later, but meanwhile it may be of interest, in closing this chapter on the Frontiers of the Solar System, to give a simple illustration of the scale of the system and of the gap separating it from the nearest stars. If we take a globe one foot in diameter to represent the Sun, a shot one-ninth inch in diameter at a distance of thirty-six yards will do for the Earth. A small marble at a distance of nearly 1,100 yards will then serve for Neptune, but for the star *Proxima Centauri*—so far as we know the Sun's nearest neighbour amongst the stars—we must obtain a small globe and place it on some spot no less than some 5,300 miles away!

From "Knowledge"

WILLIAM LASSELL

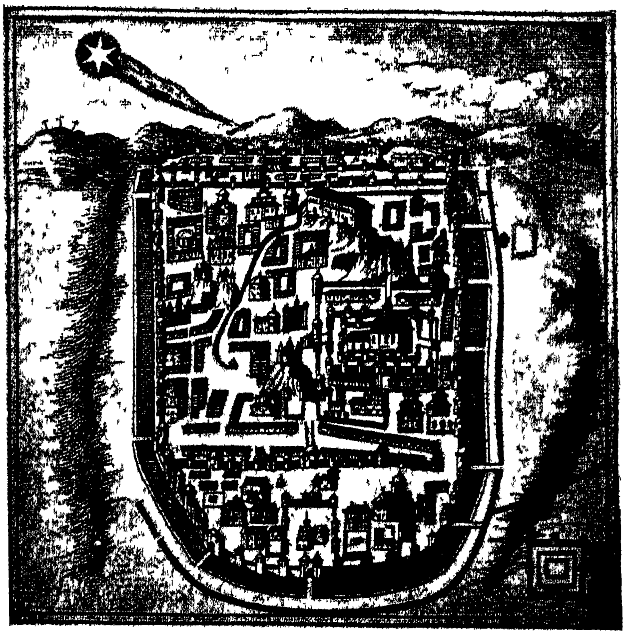
This famous English amateur observed at Liverpool, with reflectors of two and four feet aperture, in the middle of the Nineteenth Century. His observations were mainly of the fainter celestial objects, and he discovered the first satellite of Uranus and the satellite of Neptune. He also detected (simultaneously with Bond) the seventh satellite of Saturn.

CHAPTER X

COMETS

BY A C D CROMMELIN, B A , D Sc , F R A S

THERE is probably no part of Astronomy that appeals so much to the general public as that which is concerned with Comets In all ages they have excited intense interest, though formerly this was mixed up with a large amount of not unnatural apprehension , their long tails and rapid motion suggested close proximity to the Earth, and it was almost universally believed in Europe in the Middle Ages that they were luminous appearances in our own atmosphere, so that it was a short step to the supposition that they brought pestilences and other evils to mankind It was one of Tycho's useful achievements to prove, by careful observations made simultaneously at two distant stations, that Comets were at least several times as far away as the Moon, so that they must rank not as terrestrial but as celestial bodies The previous misconception as to their nature had the bad effect of making people attach very little importance to noting the exact track of Comets among the stars, so that the European records for the times preceding Tycho are extremely meagre from the point of view of orbit computation And yet a philosopher of the First Century, the famous Seneca, had made the remarkable prediction, " Some day there will arise a man who will demonstrate in what regions of the heavens the Comets take their way , why they journey so far apart from the other planets , what their size, their nature " These words remained a dead letter for 1,500 years, and then received a complete fulfilment in the discovery of the law of gravitation, which made it possible to trace the long paths of Comets and in some cases to foretell their return



[From " L'Astronomie "

HALLEY'S COMET OVER JERUSALEM, A D 66
Halley's Comet appeared in January, 66 It was probably the sword mentioned by Josephus as standing over Jerusalem (Wars, Bk VI, Chap v), shortly before its fall

Fortunately in China and Japan much more attention was paid to fixing the exact paths of Comets through the constellations This work is none the less useful to us from the fact that it was not wholly inspired by zeal for pure science , it was believed that each terrestrial kingdom had a celestial representative, and that Comets, going like ambassadors from one to another celestial region, might give useful forecasts of terrestrial events The different names given to these apparitions are of interest , the word " Comet " means hairy , it is apt enough when applied to some of these visitants (*vide* the illustrations of Morehouse's Comet of 1908) , an amusing instance is afforded by Vespasian's answer to his courtiers, who were apprehensive about the Comet of A D 79 " That hairy star does not threaten me , it menaces rather the King of the Parthians , he is hairy, while I am bald " Other fanciful Greek names applied to Comets were Xiphias, Lampadias, and Akontias , implying resemblance to a sword, a torch, and a javelin , Halley's Comet was classed as Xiphias in A D 66, and as Lampadias in A D 530 On page 415 some old drawings are reproduced, which suggest that the artists gave a good deal of rein to their fancies

The Chinese and Japanese used the designation " Besom-Star " for Comets , Suy Sing in Chinese,

Hahakiboshi in Japanese, it may be derived partly from the bundle of streamers forming the Comet's tail recalling the bundle of twigs in a broom, partly by the fancy that the tail swept up the dust in the constellations, as a broom does that on the floor. The Chinese practice of recording the length of tails in chih or cubits (somewhat over a foot) recalls the childish usage of measuring celestial distances and diameters in yards, feet and inches.

Pingré in his "Cometographie" has some vague references to Comets of thousands of years B.C., but the earliest one that rests on contemporary testimony is in 611 B.C., which opens Williams's useful book on Chinese Comets; this went through Pih Tow (our Plough) and may not impossibly have been Halley's Comet. There are stronger reasons for assuming its identity with the Comet of 467 B.C., seen both in Europe and China, and mentioned by Aristotle ("Meteor.," Book I, Chap. vii), who says that a stone fell from the sky, and that on the evening of the same day a Comet was seen. Pingré dismisses the fall of a stone from the sky as a manifest fiction. He wrote in 1783, when the celestial nature of meteors was unrecognised; but with our present knowledge the association of the fall of the meteor with a Comet strengthens our conjecture that the Comet was Halley's, for it is one of the few Comets that pass sufficiently near to the Earth's orbit to give meteor showers. Pliny adds that this meteor fell at Aegos Potami; it was as large as a chariot, and its surface was burnt; it was still shown in his time, which was centuries later.

We next find an observation of Halley's Comet in 240 B.C., and from that time to the present, with the doubtful exception of 163 B.C., we have records of its observation at every return, in most cases in language implying great brilliance.

HALLEY'S COMET IN 684

The Comet is here seen as a circular object without a tail. It occasionally looked like this in 1835. The bright star in the Bull's Eye is Aldebaran. The Pleiades are high right of the Comet.

We have already seen that in the First Century A.D. Seneca made a forecast which shows that Comets were regarded as celestial objects, so that the subsequent view, prevalent in Europe, that they were mere atmospheric exhalations was a retrograde step. There is a remarkable passage in the Babylonian Talmud, quoted in the "Observatory" (August, 1910), which I give in full:—

"Two sages of Palestine, Rabbi Gamaliel and Rabbi Josue, were making together a sea-voyage. The first had brought some bread, the second had brought, besides, some flour. When Gamaliel had eaten all his bread, he asked his companion for some flour, saying to him, 'You knew that we should be a long time on the journey, and so you took the precaution to bring flour.' Josue answered, 'There is a very brilliant star which appears every seventy years and deceives sailors. I thought that perhaps it would surprise us during our voyage and delay us. That is why I provided myself with flour.'"

M. Renaudot, discussing this passage, shows that the voyage was made about the time of the visit of the Parthian prince Tiridates to Rome in A.D. 66, in which year Halley's Comet appeared. There is therefore quite a plausible case for the assumption that the learned Jews, who kept their records very carefully, had noted the recurrence of this bright Comet at intervals of about seventy-six years (the

HALLEY'S COMET IN 1066 (FROM THE BAYEUX TAPESTRY)
The left panel shows people gazing in wonder on the Comet, "Isti mirantur stellam" This is the earliest undoubted delineation of Halley's Comet Harold's anxiety is caused by the Comet, the invasion of Tostig, and the preparations of William, symbolised by the ships

seventy in the text may be merely a round number), and so knew when to expect its return If this was so, the knowledge was subsequently lost And in any case the credit of Halley's achievement is unshaken The true orbit of a Comet could not be deduced till the central position of the Sun was known, and the law of gravitation understood, the same Comet, if it returns at different times of the year, has an entirely different track in the sky as seen from the Earth, a long calculation is required to deduce its true path round the Sun, and so test whether two Comets were moving in the same path This is what Halley did, but any identifications before his time were mere vague conjectures

Before passing on to the general consideration of the motion of Comets, there is another remarkable ancient Comet that deserves mention This is the one of 134 B C, whose appearance led Hipparchus to undertake the formation of his catalogue of stars Most text-books assert that this object was what we now call a Nova, or the sudden outburst of a bright orb in the region of the Fixed Stars Dr J K Fotheringham, in a paper read before the Royal Astronomical Society in January, 1919, showed clearly that it was a Comet It must have been a remarkable object, its splendour being compared with that of the Sun, and it took four hours to rise and set This Comet, which is also recorded by the Chinese, preceded the birth of Mithridates, a very similar object, supposed by the Chinese to be a return of the same body, was seen fourteen years later, at the time of his accession Several historians have treated these as mythical, merely intended to glorify Mithridates, but they were ignorant of the corroborative testimony from China

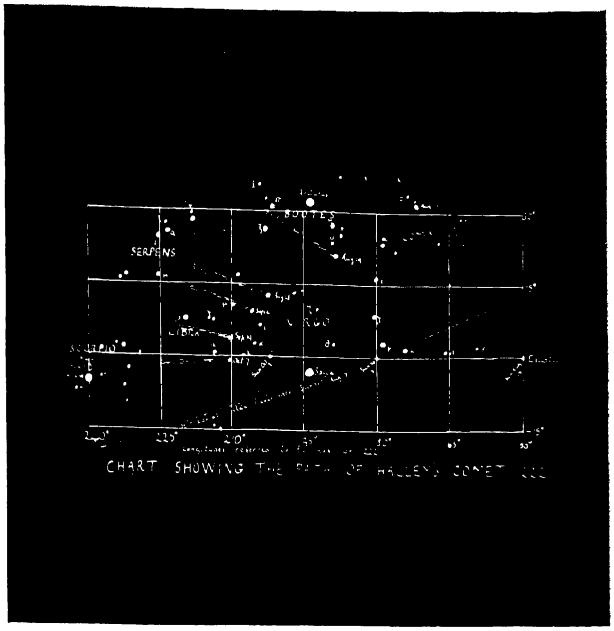
HALLEY'S COMET IN 1066
The apparition in 1066 caused great alarm, from the Comet's brightness and rapid motion It is here shown in the Twins, just after it became an evening star Castor and Pollux are seen on the left

A Comet that led to the formation of the first star-catalogue must be for ever memorable

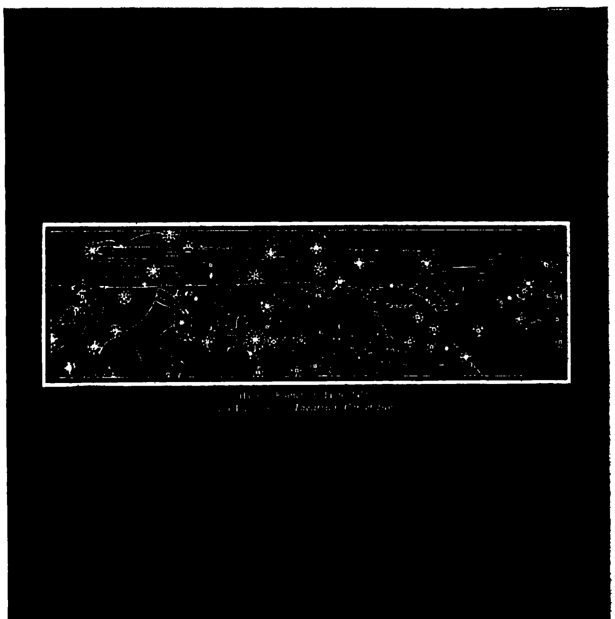
It seems appropriate to give at this point, some account of the nature of Comets and their orbits, before continuing the history of their appearances As soon as Kepler obtained his result that the paths of the planets round the Sun are slightly flattened ellipses, it was a natural suggestion that Comets might move in elongated ellipses or parabolas, Hevelius, Borelli, Lower, Dorfel, all appear to have advanced these ideas before the publication by Sir Isaac Newton of the law of gravitation After this the matter was no longer one of mere conjecture, but was capable of exact demonstration Newton showed that the four curves known as conic sections were all possible forms of orbits under gravitation These curves can all be seen as shadows thrown by a round plate on a white wall, using as small a source of light as possible, so as to obtain sharp shadows, when the whole of the plate is nearer to the wall than the flame, the shadow is an ellipse, becoming a circle in particular cases, one of which is when the plane of the plate is parallel to the wall If the outer edge of the plate is just as far from the wall as the flame, the shadow becomes a parabola, which is simply an ellipse whose length has become infinite If the plate is moved farther out the shadow becomes a hyperbola; this contains two branches, but only one appears as a shadow

The other branch would be formed by drawing lines from the outer part of the rim through the flame, and carrying them on to meet the wall, this outer branch can never be described under the force of gravitation alone, as that must always give a curve that is concave, not convex, to the attracting body, but we shall presently show that the tail-matter gives evidence of a repulsive force in the Sun, stronger than gravitation, and the outer branch of the hyperbola is precisely the path that would be described by tail particles (assuming that the repulsive force resembled gravity in obeying the law of the inverse square of the distance)

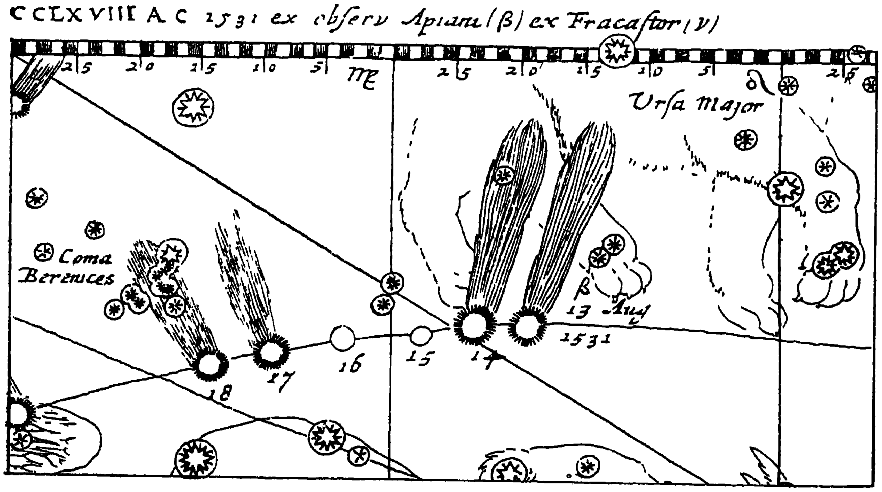
A picture of the hyperbola with its two



HALLEY'S COMET IN AUGUST AND SEPTEMBER, 1222
The Comet was very brilliant in 1222, the Moon looking pale beside it It passed through Bootes (the Herdsman), the Virgin, the Scales and the Scorpion



HALLEY'S COMET IN 1456
The Comet appeared in July, 1456 Its head was in the Twins, its tail, 60° long, crossed the Crab and the Lion The siege of Belgrade was in progress, the Comet is said to have discouraged the Turks and contributed to their defeat



[From "L'Astronomie"

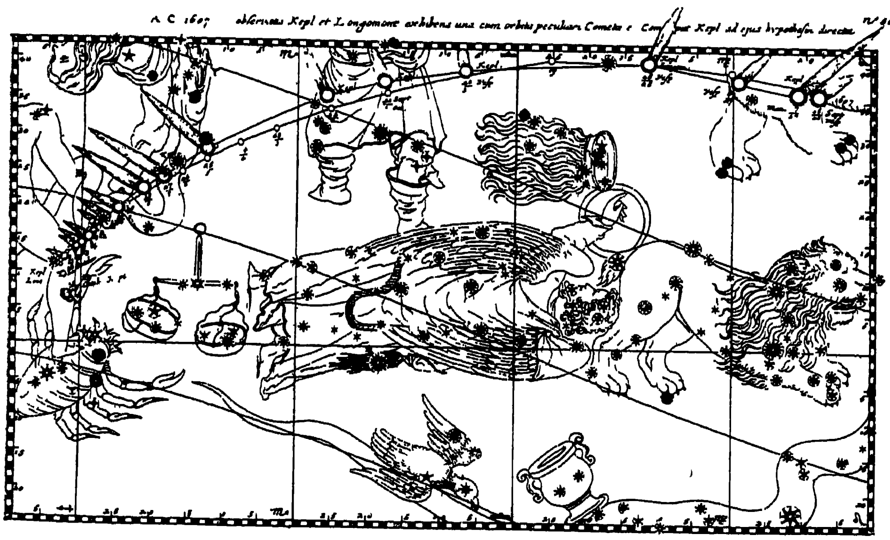
PATH OF HALLEY'S COMET IN 1531

The path of the Comet was under the legs of the Great Bear, and the Hair of Berenice The positions were determined by Apian and Fracastor This was the first apparition used by Halley

branches is given on page 430, as we pass along the curve from the vertex, it becomes straighter and straighter, and continually approaches two lines called asymptotes (Greek for "not falling together") so that the distant parts of the curve become practically coincident with them In the picture these lines are at right angles, but this need not be the case

Another application of the hyperbola in Astronomy is in the study of the bending of light rays by gravitation, which was predicted by Einstein and verified during recent eclipses

The parabola is a familiar curve to most people, though they may not know its name, it is the course followed by a ball thrown up obliquely, or by the jet of water from a hose or fountain It may be drawn on squared paper, by selecting a point as vertex, then measuring various distances to the right, say, $\frac{1}{2}$, 1, $1\frac{1}{2}$, 2, $2\frac{1}{2}$, etc, and measuring the squares of these distances downwards (that is, $\frac{1}{4}$, 1, $2\frac{1}{4}$, 4, $6\frac{1}{4}$, etc), the points thus fixed will lie on the curve, which has a symmetrical portion to the left of the vertex It is drawn on page 429, the figure also shows a useful property of the velocity at any point in a parabolic orbit about the Sun, it can be split into two equal constant velocities, one at right angles to the axis, the other at right angles to the line joining Comet to Sun, the two are in the same direction at the vertex, and the velocity here is greatest, the farther we go from this point the greater is the angle between the two directions, and the smaller the resulting speed



[From "L'Astronomie

PATH OF HALLEY'S COMET IN 1607

The picture shows the path of the Comet through the hind legs of the Great Bear, the Herdsman, the Serpent, Ophiuchus The change in the length and direction of the tail is indicated This was the second apparition of the Comet used by Halley

It can easily be deduced from Kepler's third law that the speed of bodies moving in circular orbits is inversely as the square root of their distance

from the Sun The Earth moves eighteen and a half miles per second, at nine times the distance the speed would be one-third, or six and one-sixth miles per second, at 100 times the distance one-tenth, and so on Just as there is only one circular speed at any distance, so there is only one parabolic speed at any distance, and it is always greater than the circular speed in the same proportion, which can be shown to be the square root of two, or 1 414 Thus an increase of the Earth's speed by seven and a half miles per second, making it twenty-six miles, would suffice to make it move in a parabola, and to carry it away from the Sun Similarly all Comets moving in parabolas have a speed of eighteen and a half miles per second when at twice the Earth's distance from the Sun

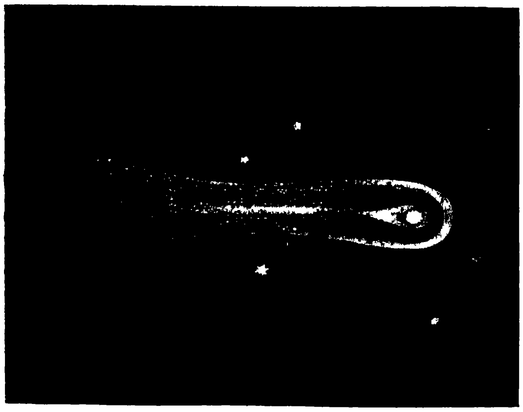
[After Hevelius

HALLEY'S COMET IN SEPTEMBER, 1682

This appearance of the Comet was shortly after the discovery of the Law of Gravitation The period of the Comet was determined by the observations of 1682, combined with 1531 and 1607 The curious curved ray from the head was also seen in 1759 and 1835

The speed at any point determines at once the character of the orbit and the period, if the speed is greater than that of a parabola, the orbit is hyperbolic, if less, elliptic If a shell were to burst at any point in space and scatter its particles with the same speed in all directions (less than the parabolic speed) the particles would all have the same period, and would all meet again after one revolution So we see that if a planet diminishes a Comet's speed, it shortens its period and brings it back sooner, Jupiter did this to Halley's Comet in 1835, the revolution from then to 1910 being the shortest on record

A body coming from a great distance, with just enough velocity to start with to avoid falling into the Sun would describe a parabola, if it had considerable speed to start with, it would describe a hyperbola, in the latter case it would circle once round the Sun, and then leave it for ever However, no Comets with decidedly hyperbolic orbits have been seen, the conclusion is that Comets do not come from other solar systems, but all belong to the Sun's family The few cases of a slight tendency to a hyperbolic path can be explained



[From Himmel und Erde

HALLEY'S COMET IN 1759

This was the first predicted return of Halley's or any other Comet It was not particularly brilliant in 1759, but the luminous jet behind the head was seen as in 1682 and 1835

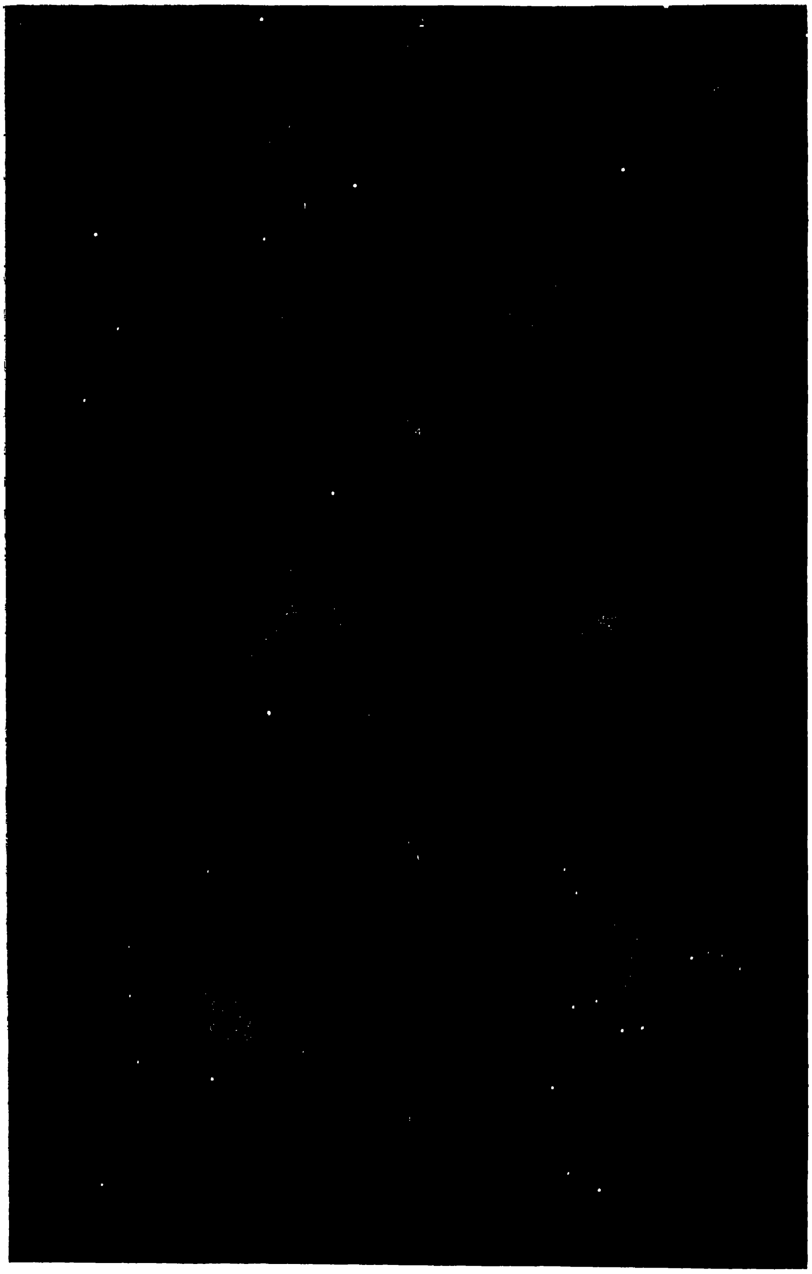
By permission of] [H P Hollis

VERIFICATION OF HALLEY'S PREDICTION IN 1759

A French artist (name unknown) depicts an angel calling Halley from the grave to witness the fulfilment of the first prediction of the Comet's return at a given date

by disturbances produced by the planets These disturbances are often very large, since the elongated paths of Comets take them across the routes of the planets, and close approaches are not infrequent

The great majority of Comets move in paths that are practically parabolic This does not mean that their orbits really go to infinity, for we have just seen that they are to be regarded as members of the Solar System, but we can only observe them for a very small portion of their orbits, and in this region the departure from a parabola is in most cases too small to detect Further, parabolic motion is much simpler to compute than motion in a long ellipse, all parabolas are of the same shape, and tables have been made which serve for all cases, whereas in ellipses separate tables are needed for all values of the eccentricity



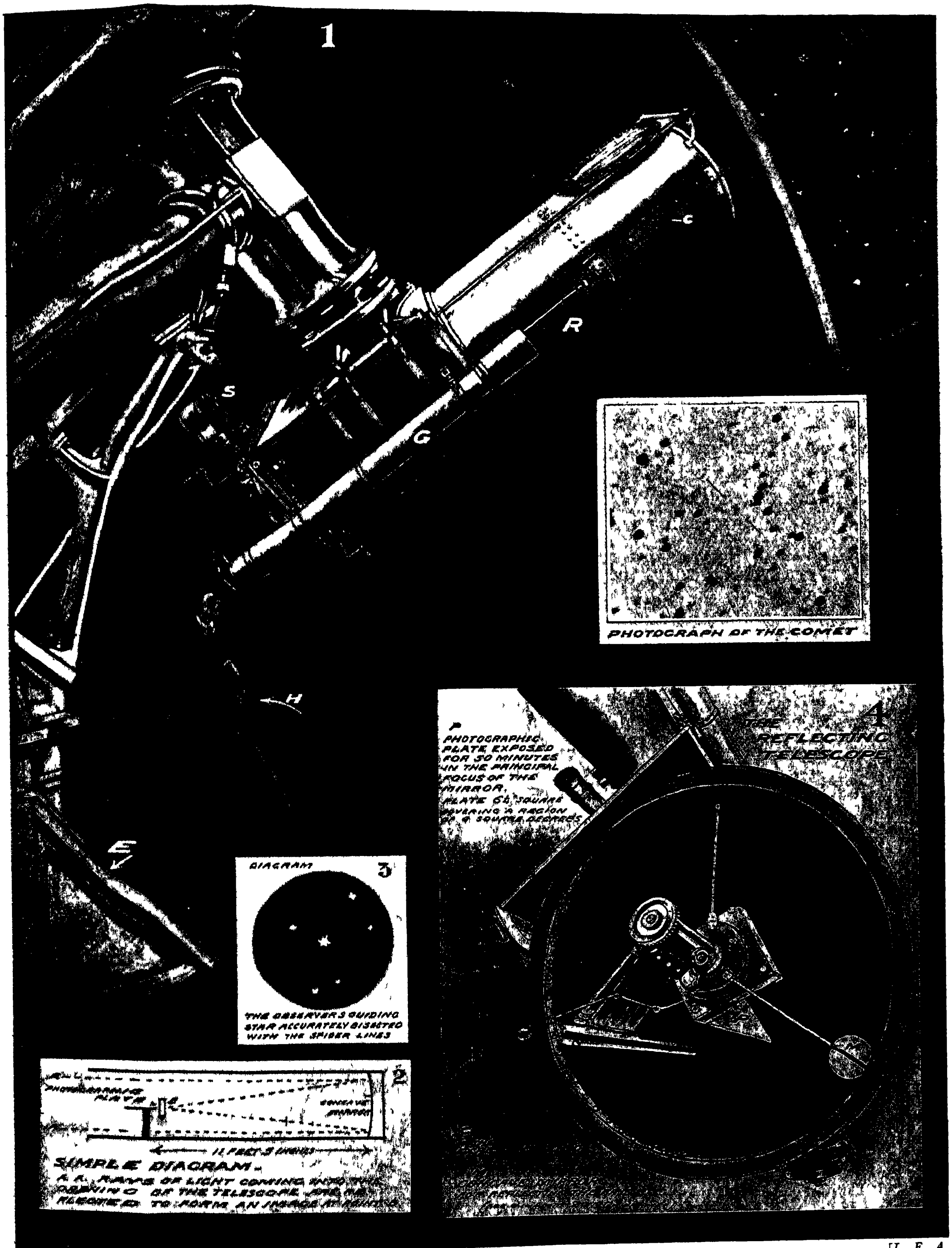
[After Guillemin

HALLEY'S COMET (SIR J HERSCHEL)

1 View of the Comet in Ophiuchus with the naked eye, 1835, October 22 2 The same viewed with a telescope of seven feet focal length 3, 4, 5, 6 Details of the head of the Comet, 1835 October, 1836 February The Comet showed remarkable changes from night to night in the telescope The bright spur behind the nucleus is a recurring feature of this Comet

It seems that the vast extent of the cometary orbits, which go out to at least twenty times Neptune's distance from the Sun, probably much more, implies one of two things either the material forming the Solar System was once spread out over this huge volume of space, or the tidal disturbance, which the planetesimal hypothesis supposes to have taken place from the approach of another star to the Sun, resulted in a distribution of matter over a space much wider than the known planetary orbits There is no reason to suppose that a very large proportion of the matter went to these distant regions, for Comets, though large, are exceedingly tenuous, and probably the combined mass of all the Comets ever observed is much less than that of the Moon

Newton found an able ally in Halley in the application of the law of gravita-



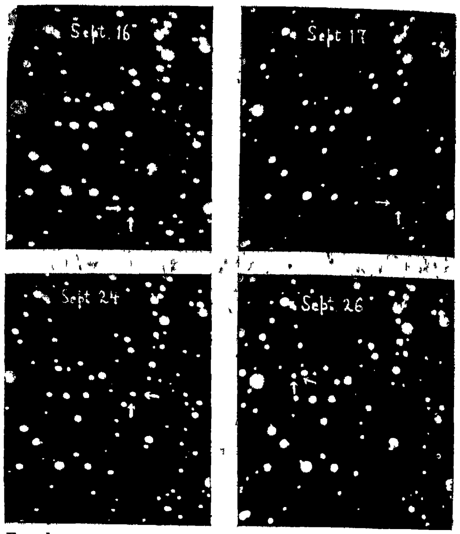
By permission of] [*L E A*

PHOTOGRAPHIC SEARCH FOR HALLEY'S COMET AT GREENWICH, IN SEPTEMBER, 1909

Mr Davidson is here seen taking photographs with the thirty-inch reflecting telescope He looks through the guiding telescope, which has a cross of spiders' webs at the focus (see No 3), he keeps a selected star at the cross, using an electric key H, which regulates the rate of the driving clock No 4 shows the position of the plate-holder P, which receives the light from the great mirror M The reproduced negative shows the Comet in the centre, indicated by two sloping lines It appeared just like a small star, but its motion between one photograph and the next permitted its identification

tion to Comets The latter seems to have had more aptitude for tedious arithmetical calculations than Newton, and he immediately collected all the observations of the positions of Comets that he could find, they extended over the preceding two centuries and included twenty-four Comets In each case a parabolic orbit was assumed in the first instance, which indeed is still the practice This was indeed quite near enough for the Comets that he dealt with, nowadays we should be able to say after a month's observations that a Comet was not moving in a parabola, if its true period was eighty years, or so But the observations used by Halley were much rougher, and this was not possible

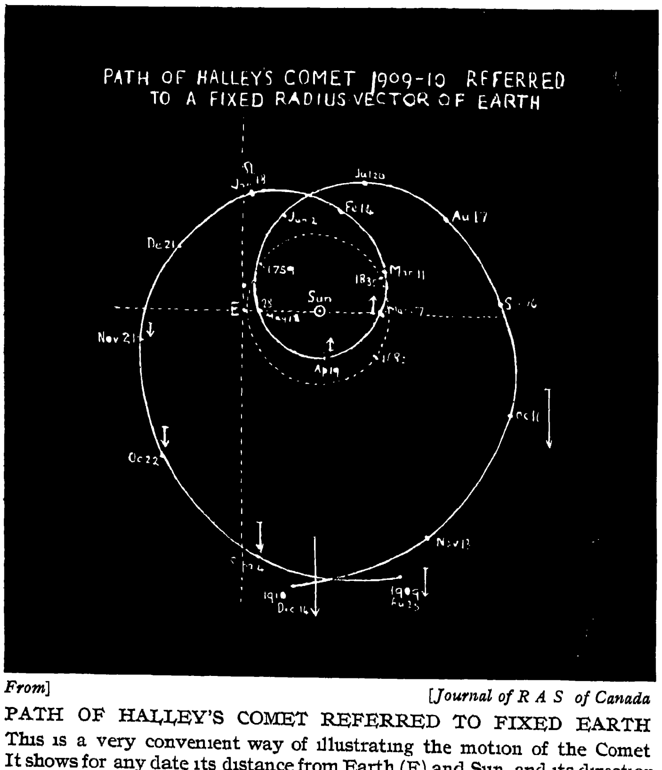
On obtaining the orbits of twenty-four Comets, Halley compared them, and noticed that three of them, those of 1531, 1607 and 1682, were practically identical, and he at once suspected that this was the same body returning at intervals of three-quarters of a century He hesitated slightly when he noticed that the first interval was fifteen months longer than the second, but he noticed that the Comet must have passed fairly near to the two great planets Jupiter and Saturn, these bodies influence each other's periods to a quite appreciable extent, and



From] [Yerkes Observatory

EARLY PHOTOGRAPHS OF HALLEY'S COMET, SEPTEMBER, 1909

The photographs were taken on September 16, 17, 24, 26 The same stars appear on all four plates The Comet is indicated by arrows It looks exactly like a small star, but its motion enables us to identify it The earliest photograph was taken at Helwan on August 24



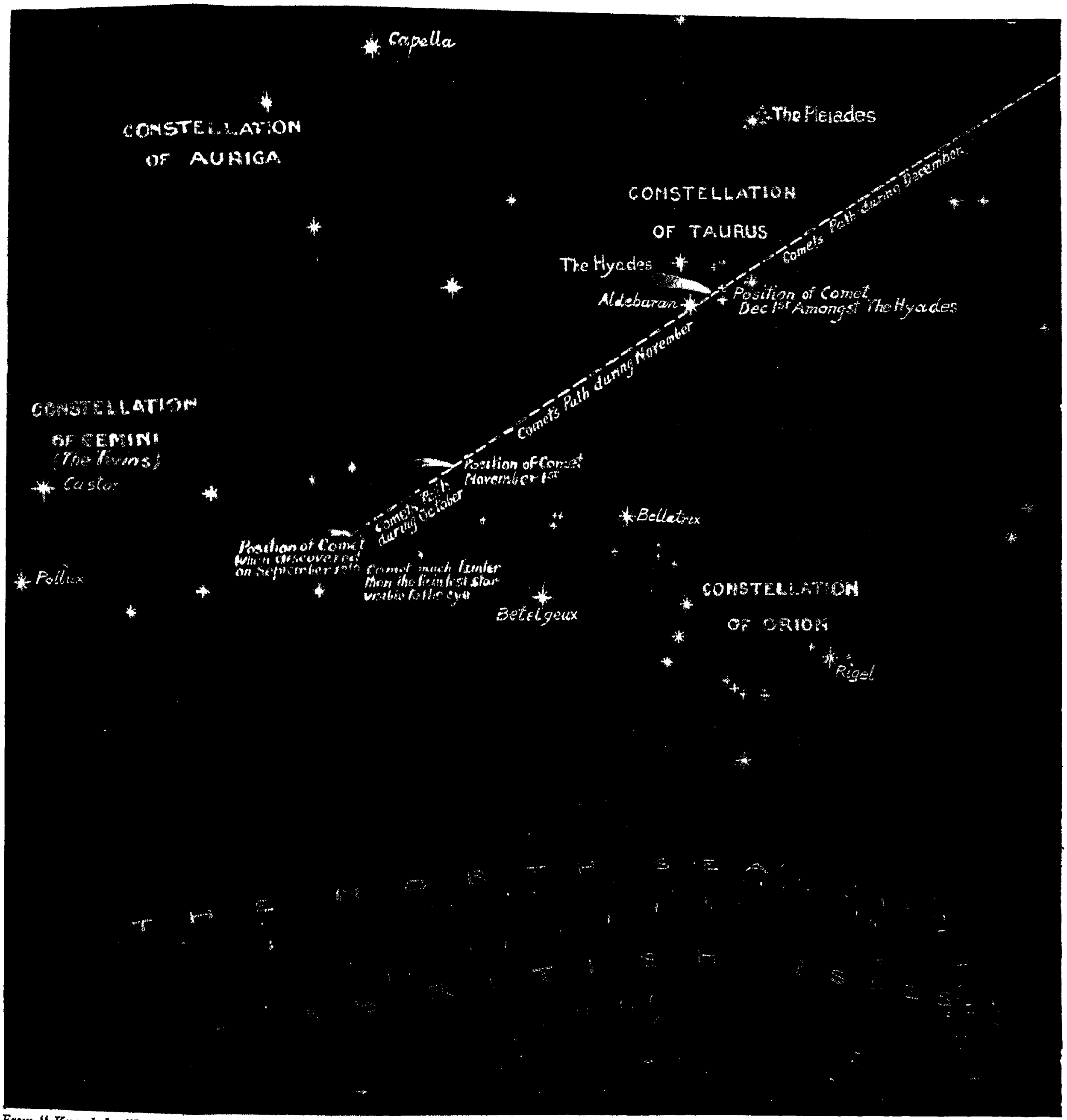
From] [Journal of R A S of Canada

PATH OF HALLEY'S COMET REFERRED TO FIXED EARTH

This is a very convenient way of illustrating the motion of the Comet It shows for any date its distance from Earth (E) and Sun, and its direction relative to the Sun The position for 1909, August, is low right, that for 1910, December, low left The same curve will serve for other returns, altering the position of E, its positions for 1682, 1759, 1835, are shown The position for 1986 will be a little above that for 1759

their influence on the Comet would be much greater, both on account of its closer approach to them, and because its greatly elongated orbit (*see* p 74) is far more sensitive to changes of period than a circular orbit Halley was quite correct in this reasoning, which was the more creditable in that the study of perturbations was still in its infancy, and had not been reduced to a system He then looked farther back, and was confirmed in his view by seeing a record of a Comet that was evidently the same appearing in the summer of 1456 He tried to go still farther back, but here he went astray, and though he made a list of supposed returns extending to the one that marked the birth of Mithridates, he was wrong in every case before 1456 This does not affect his credit, as these identifications were only given as conjectures, whereas now the study of planetary perturbations enables us to make the identifications certain

Looking forward, Halley announced



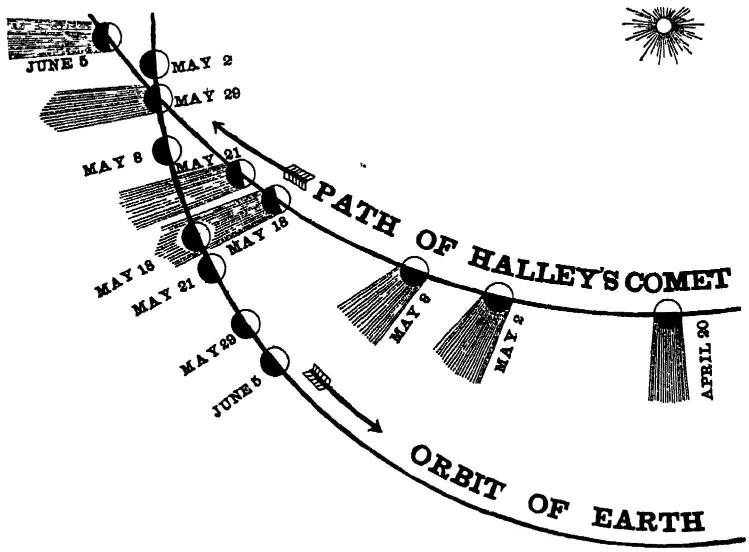
From "Knowledge"] [*By permission of the "Daily Graphic"*

PATH OF HALLEY'S COMET AMONG THE CONSTELLATIONS DURING AUTUMN, 1909

The Comet was in the western part of the Twins when found It will always be first seen in this neighbourhood, if found when still a long way from the Sun It moved slowly back through the Bull, the Ram, and the Fishes, it was then stationary, after which it moved in a forward direction over nearly the same path as before, passing on as an evening star through the Twins, the Crab, and Hydra

that the Comet would reappear towards the end of 1758 or beginning of 1759, he allowed a little (not quite enough) for delay due to the planets, actually it passed nearest to the Sun on March 12, 1759 Halley knew he could not live to see the return, and conscious of the unique interest of the occasion, when for the first time in the world's history the date of the return of a particular Comet was definitely announced, he asked posterity to remember that this first prediction was made by an Englishman Strangely enough, it was in England that the prediction received least honour, the *Gentleman's Magazine* in 1758 published some verses expressing disbelief in the forecast, while in France, Clairaut and Lalande, assisted by Madame Lepaute, spent two years in computing the planetary perturbations They obtained a result near the truth, fixing the time as April 13, one month too late, the masses of Jupiter and Saturn were not very exactly known, while Uranus and Neptune had not been discovered

Halley had called this body "a Mercury among Comets," supposing it to have the shortest period of any of them We know at present quite a number of them with much shorter periods, the true Mercury among them is Encke's Comet, which returns every three and one-third years, it shares with Halley's the distinction of being seen at every return But Halley's remains the only periodic Comet that is conspicuous to the naked eye All the other brilliant Comets have such long periods that they have not been seen at a previous return since Astronomy became an exact science, they cannot be predicted, and take us by surprise when they come

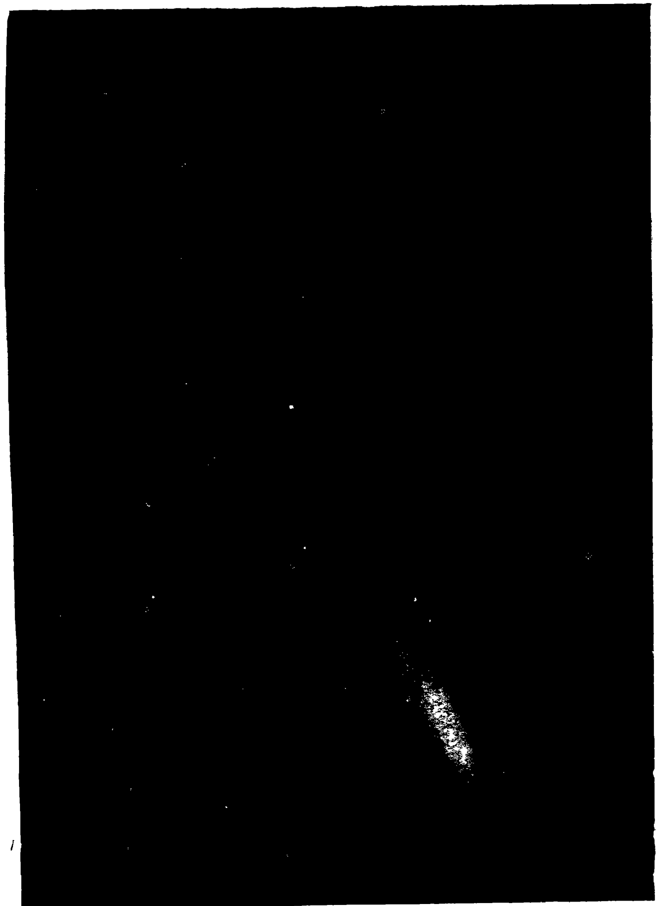


PATH OF HALLEY'S COMET, MAY, 1910

This picture shows how the Earth and Comet, moving in opposite directions, were nearest to each other on May 18 Actually, the tail was curved backwards, which somewhat delayed our passage through it The head of the Comet transitted the Sun, but was quite invisible when doing so

The calculations that are made of the return of periodic Comets are based on the assumption that nothing except gravity is acting upon them, these predictions agree well with the facts, which proves that this is practically true, but we have, on the other hand, the fact that the tails of Comets are manifestly being repelled by the Sun with a force much stronger than gravity This force therefore does not affect the head of the Comet, we draw the conclusion that the non-gravitational forces are only important on very tiny particles comparable with a wave-length of light (say $\frac{1}{50000}$ inch in diameter) and that the matter forming the head of the Comet is in pieces that are much larger than this We are led to the same conclusion in another manner Immense supplies of gas are driven away from the head into the tail, these are permanently lost to the Comet, whose attraction is far too weak to reclaim the matter sent out Tiny particles could not hold much gas, and would give it all out quickly, but Halley's Comet has been sending out large tails at each return for over 2,000 years, which implies that the lumps forming the head are fairly large We cannot, however, imagine that their diameter runs into miles, for in that case something would have been seen of the head of the Comet when it transitted the Sun in May, 1910 I should put down the diameter as several feet, probably larger than the largest meteoric fragments in our museums (*see* page 109)

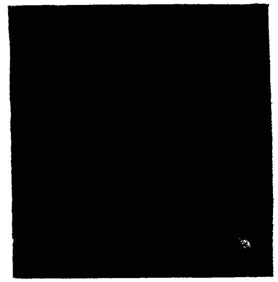
There are quite independent reasons for supposing that the head of a Comet consists of meteors Prof J C Adams studied the orbit of the Leonid meteors of November with great care, and found



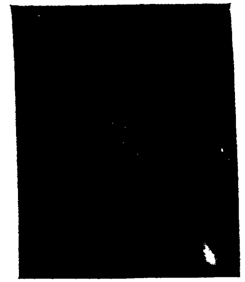
Photographed at the] [*Transvaal Observatory*

HALLEY'S COMET 1910, MAY 1

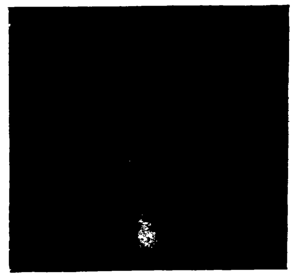
Many people in England talked of Halley's Comet in 1910 as a disappointing failure This beautiful photograph is sufficient evidence that the failure was not in the Comet, it was due to its low altitude in England, combined with twilight



May 5, 3 15 3 45 a m. C S T



May 13, 3 10 3 37 a m. C S T



May 25, 9 05 9 35 p m C S T

May 29, 9 17 9 55 p m C S T

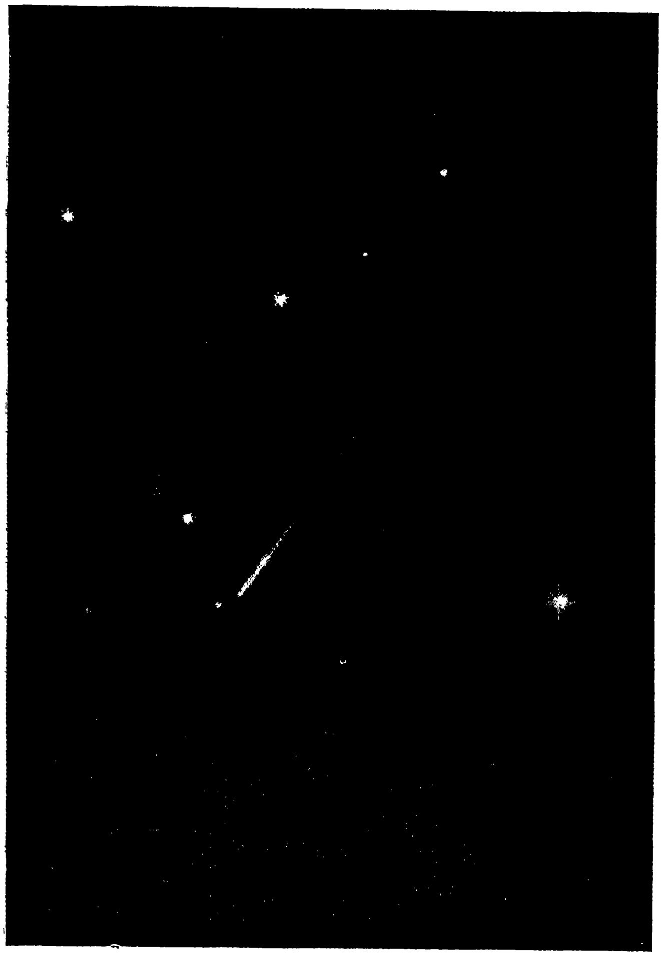
May 30, 9 20 9 60 p m. C S T

June 5, 10 0 10 30 p m C S T

HALLEY'S COMET, 1910 (D W MOREHOUSE)

An interesting series of photographs taken by Mr Morehouse (discoverer of the remarkable Comet of 1908) The tail was increasing in size up to May 18, then diminishing

that their orbit agreed with that of Tempel's Comet of 1866 (period about thirty-three and a quarter years) Schiaparelli found a similar agreement between the orbit of the Perseid meteors of August and Tuttle's Comet of 1862 The Lyrids of April are associated with Thatcher's Comet of 1861, the Andromedes of November with Biela's short-period Comet, which split in two, and subsequently ceased to exist as a Comet, though the meteors from it still remain Halley's Comet itself has a meteor shower, the Aquarids of May Its orbit does not quite intersect that of the Earth, but passes within a few million miles of it, and the meteors are dispersed for some distance all round the cometary orbit (*see* picture on page 398) The meteor that fell at Aegos Potami in 467 B C may well have been a member of this shower

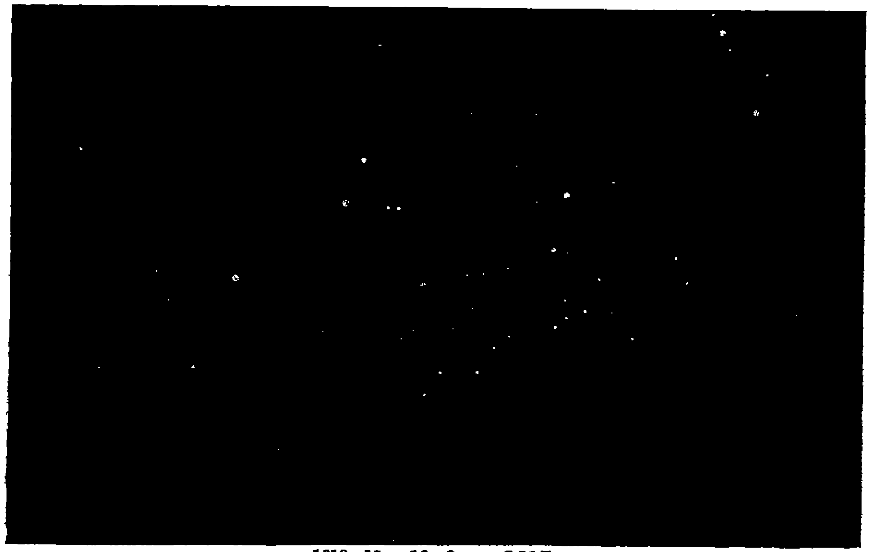


HALLEY'S COMET, NAKED-EYE VIEW IN MEXICO
(L G LEON)
This picture shows the Comet near the square of Pegasus Venus is shown to the right of it

Probably when a Comet is a long way from the Sun, it has little in the shape of gaseous envelopes The photographs of Halley's Comet taken in September, 1909 (*see* page 396) show no nebulosity, the Comet looks exactly like a small star, and can only be distinguished by its motion Its tail did not begin to appear till some months later, this is the general rule in Comets with tails that the latter is not seen at first, but gradually develops during the approach to the Sun It may be simply the Sun's heat that draws the gas out of the meteoric lumps, just as coal is heated in retorts to extract its gas Once the gas is extracted, it forms the coma, which is a more or less spherical envelope round the head Some repulsive agency then begins to act on this, driving matter out away from the Sun to form the tail The generally received idea is that this repulsion arises from light-pressure, which is known to exert a strong outward force on particles whose diameter is comparable with a wave-length of light The difficulty about this is that the spectroscope shows the tail to consist largely of gas, whose molecules are so much smaller than the size mentioned, that light-pressure for them would be very small, it has been suggested that the dust particles that are driven out might drag a good deal of gas with them There is, however, another agency that almost certainly assists in the action, viz, electrical repulsion Several of the photographs and pictures of Comets accompanying this chapter show that the tail leaves the head not in a single jet, but in a number of them that spread out like a fan The most notable case is the six-tailed Comet of 1744 (page 105)

I will here recall Kepler's Law of Equal Areas (*see* pages 83, 87) Newton had no difficulty in proving from this law that the planets are acted on by a force directed exactly towards the Sun In fact, any force that is always directed to or from a point has no effect on the rate of description of areas of any body moving round that point From this it can be shown by simple geometry that if the tail were

1910 May 18, 9 a.m. G.M.T

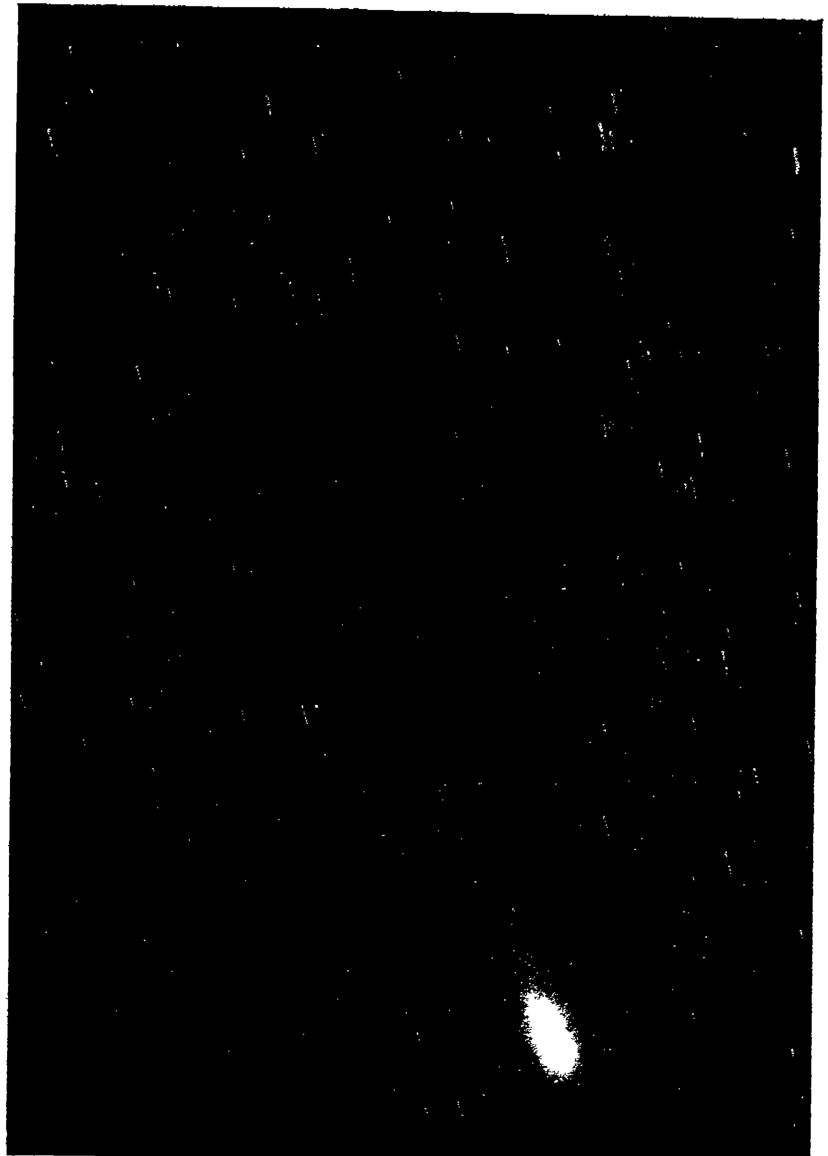


1910 May 19 9 a.m. G.M.T

From] [Astrophysical Journal

DRAWINGS BY PROFESSOR BARNARD OF THE TAIL OF HALLEY'S COMET MAY 1910

The rapid narrowing of the right extremity of the tail is a perspective effect, this portion being much more distant than the part farther left. The stars are very carefully drawn Pegasus the Eagle, and the Head of the Waterman being shown A faint broad extension is visible below the main tail. The Earth must have traversed this but the brightest part of the tail probably passed above it The low left portion of the tail is perceptibly wider in the second drawing owing to its approach to the Earth.

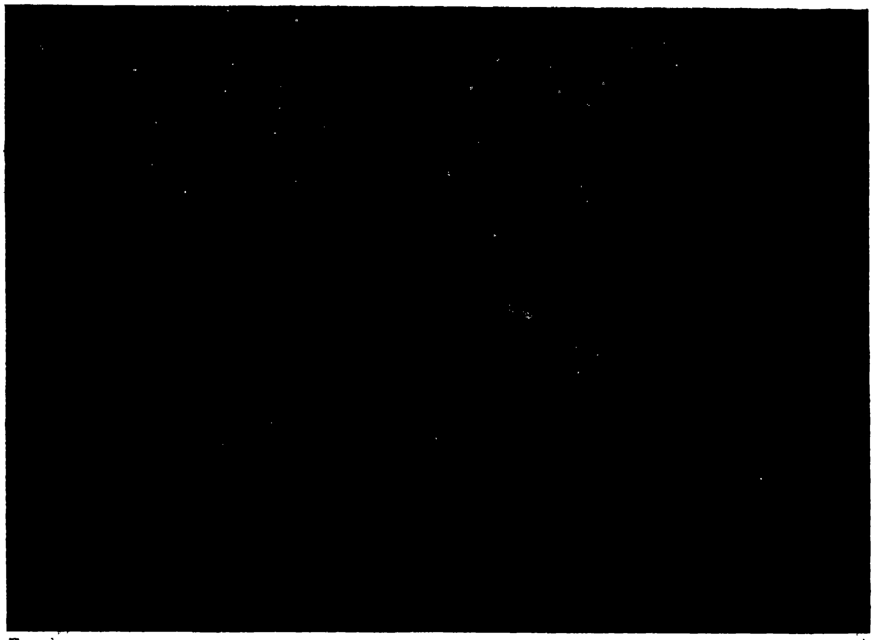


[From] [Astrophysical Journal

HALLEY'S COMET PHOTOGRAPHED BY PROFESSOR BARNARD EVENING OF 1910 MAY 29

The display of the Comet in the evening sky was less grand than in the morning sky The chief interest of this picture is the narrowness of the tail its bright portion is narrower than the coma. The Comet at this time was travelling with its tail in front not behind as many people imagine to be the rule

simply caused by solar forces, it would always issue from the head exactly in the line joining Sun and head That it does not do so is made manifest by these fan-shaped tails There are therefore non-solar forces concerned in making the tail, and we cannot locate these elsewhere than in the Comet's head Noting that the force required is a repulsive, not an attractive, one, it seems impossible to suggest anything except electrical repulsion We have practically demonstrated this for the head of the Comet, and it seems a natural deduction that the Sun's action is also electrical, though light-pressure may help it The Comet that gave most information on the physics of Comets' tails was that of Morehouse, which appeared in the autumn of 1908 It was not very conspicuous to the eye, but was very rich in photographic rays (*see* p 61), so that the photographs of it are full of interest They appear to show that a good deal of the tail-matter leaves the head in the first instance towards the Sun, but it is quickly turned round by the solar repulsion, and sent backwards in two streams, one on each side of the head, with a darker space between them An analogy has been put forward of a fountain that is sending up jets in many directions, but after it has gone up a little way gravity makes the water descend, the outline of the water forms a parabolic curve, and we often see these parabolic hoods on the sunward side of the head These are well shown in the picture of the Comets of 1858 and 1861, page 420. Coggia's Comet of 1874 also shows them Morehouse's Comet was high up in the northern sky for the greater part of the night, so that it was possible to take a long series of photographs These clearly show outward motion of the small luminous knots that can be detected in the tail, and enable the intensity of the repulsive force to be measured It was found that some of these left the head with accelerated motion, but that after a time the acceleration died away This again suggests electrical forces, since this effect might be due to the leaking away of a charge, whereas light-pressure would not be subject to any sudden change



From] [" *L'Astronomie* "

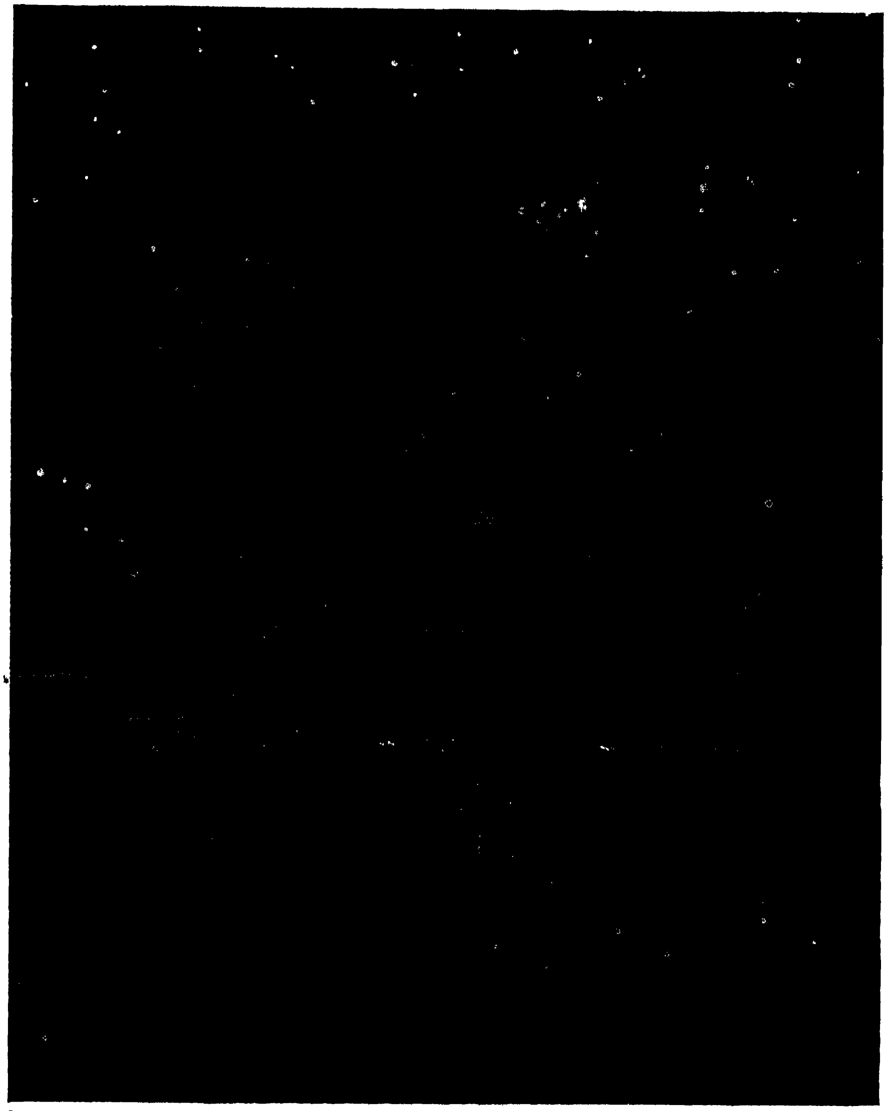
HALLEY'S COMET IN THE EVENING SKY, MAY, 1910

This picture, made in Italy, shows the beautiful aspect of Halley's Comet in the evening sky over the Alps in May, 1910 The Sickle of the Lion is shown above it, and the Head of Hydra below it

Again, the whole process of tail emission was far from uniform, and would sometimes cease for a time, so that an old discarded tail would be seen passing away, with a gap between it and the new one The same effect was seen in a photograph of Halley's Comet in April, 1910, and it was noted that this Comet temporarily lost its tail in 1835

Some tails have undergone periodic changes of form, that suggested rotation There are, however, mechanical difficulties in the way, since a body can only rotate if it is rigidly held together, or acted on by a strong central force Neither of these can hold in this case, so the only supposition that we can make is that a rotation of the head might give an appearance of rotation in the tail that flows from it

Actually the streamers of the tail would have a spiral or helical form Such a form is suggested by some photographs that Prof Barnard took at a short interval, and combined in a stereoscope, though he pointed out that the appearance could be explained in other ways Bredichin, a well-known Russian astronomer of the last century, made a classification of Comets' tails, which should be mentioned in the history of the subject, though the evidence since accumulated does not altogether bear out his conclusions He postulated three types (I) long straight tails, like that of the Comet of 1843, (II) slightly curved tails, like the principal tail of Donati's Comet, (III) short, greatly curved tails, which are not often seen His view was that these tails indicated a difference in the amount of the repulsive force compared with gravitation, he ascribed this to a difference of the molecular weights of the particles He supposed type I to be composed of hydrogen, the repulsive force being some twelve times that of gravity Type II he ascribed to hydrocarbon compounds, this is the commonest form of tail, and the spectroscope supports him in showing the presence of these compounds, though it has not shown the tails composed of pure hydrogen that he postulated in I Type III (in which the repulsive force was supposed to be only a fraction of gravity, owing to the greater density) was put down to particles of iron vapour, possibly mixed with sodium, etc Sodium has been spectroscopically indicated in a few cases, but the spectroscope hardly bears out Bredichin's idea that each separate tail has a different chemical composition, photographs of the tail of Morehouse's Comet taken with a prismatic camera, seem to show much the same chemical composition in the different tails



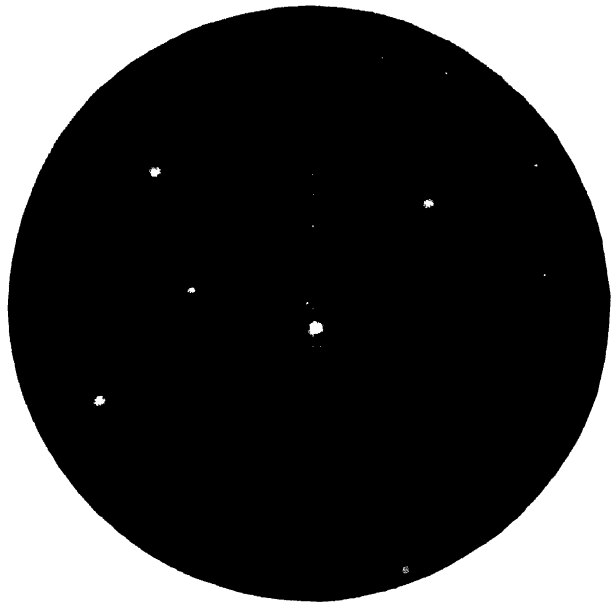
From] [" L'Astronomie "

HALLEY'S COMET SEEN FROM PARIS, MAY, 1910

The Comet is here shown in the morning sky, with Venus and the Moon to the right of it The Eagle and Dolphin are shown in the top right hand corner Even a short southward journey sufficed to make the conditions for observing the Comet notably better than in England

The career of a Comet may be said to be over when its meteors have lost all their gas, or when they

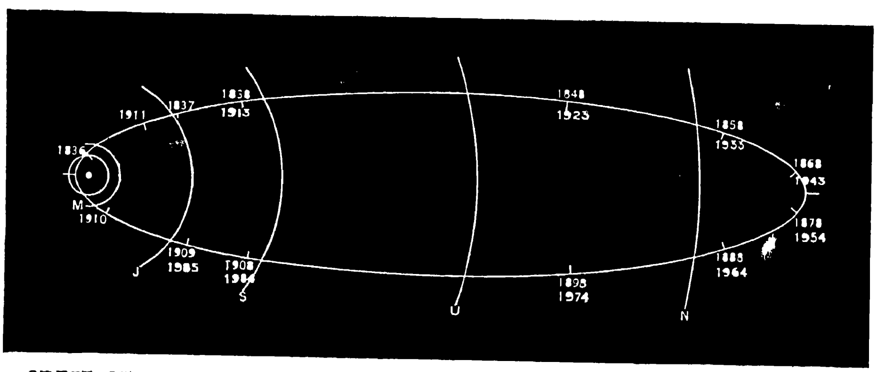
have been scattered by perturbations over so wide a space that its unity and visibility are lost These disrupting causes are most effective when a Comet is fairly near the Sun, therefore the oftener that a Comet approaches the Sun, the shorter the period of its existence as a Comet I think, therefore, that we can ascribe the great prevalence of long-period Comets to the principle of " The survival of the fittest " We are apt to be deceived, on looking at catalogues of Comets, we see a considerable number of short-period ones among them, and we may think that they are in a majority, or at least in a strong minority But the short-period ones are like a stage army, they multiply themselves by their repeated entry into our stage, whereas the long-period ones make their single entry and are then done with as far as the human race is concerned From a study of the catalogues I estimate that something like 300 long-period Comets approach the Sun in a century I do not think that I am over-estimating the average period of those Comets whose orbits are indistinguishable from parabolas if I put it at 40,000 years, or 400 centuries This would give one-eighth of a million as the total number of long-period Comets, so that they seem to be by far the most numerous class of objects in the Solar System Even if we accept the rather extreme estimate of 50,000 asteroids, they are still outnumbered by more than two to one The short-period Comets, even with a generous allowance for undiscovered ones, cannot much exceed 100 By far the greater number of them are connected with the giant planet Jupiter, and new members of his family are continually being found These bodies have presumably a comparatively short career, two of the family, Biela's and Brorsen's, are definitely written off as defunct This brings us to the second method of cometary dissolution, by the scattering of their constituent meteors through perturbations



CURIOUS ASPECT OF THE HEAD OF HALLEY'S COMET, 1910, JUNE 8 (L G LEON)

The hoods round the head of the Comet here present a much broader and more irregular outline than is usually the case

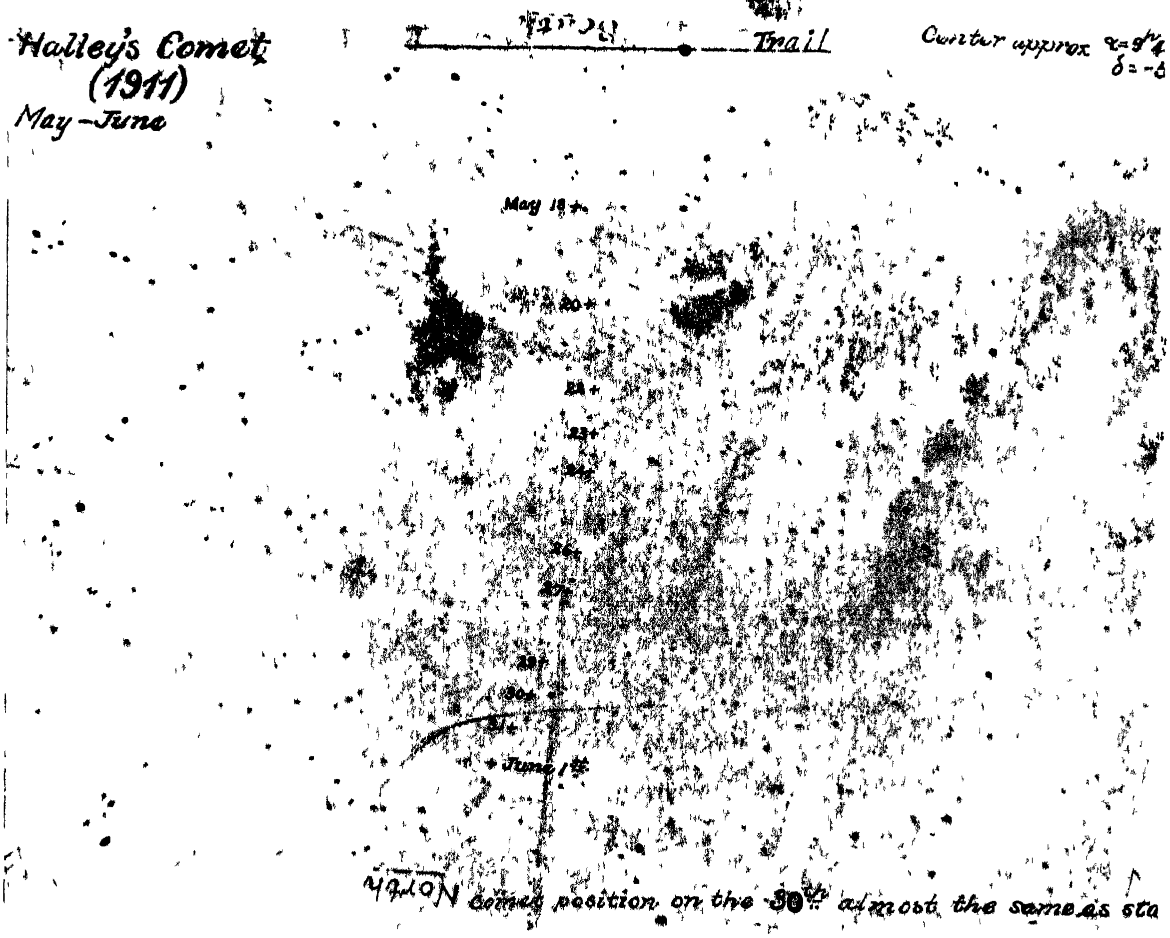
The mass of Comets is known to be small compared with that of even the satellites Several Comets are known to have passed right through the Jovian system without producing the smallest appreciable derangement of the satellite movements This shows that the grip of a Comet on its constituents must be a very loose one, and once scattering begins it proceeds at an accelerated pace, for henceforward the separated fragments are subject to different perturbations It is in this manner that we must suppose the



ORBIT OF HALLEY'S COMET, WITH DATES OF PASSING CERTAIN POINTS

The figure should be studied, to realise the remarkable change in the Comet's speed It is now midway between the orbits of Uranus and Neptune, and will remain for thirty-two years outside Neptune's orbit It passes aphelion in 1948

meteor showers to have originated The mode of scattering of these is quite distinct from that of the tail particles The latter are driven off, not along the Comet's orbit, but in a direction away from the Sun, the meteors, on the other hand, continue to travel in almost the same orbit as the Comet (*see* picture, page 427), they have not been separated by the repulsive force, but by slight differences of attractions and perturbations It is noteworthy that all the Comets that are known to be associated with meteor showers are of moderate period The periods are Thatcher's Comet, 415 years, Tuttle's, 130 years, the others being seventy-five, thirty-three, and seven years It is evident that repeated disturbances are required to draw out the meteors into these long streams How long they are is shown by the fact that we see some Leonids and Perseids every year, so that they must form a band

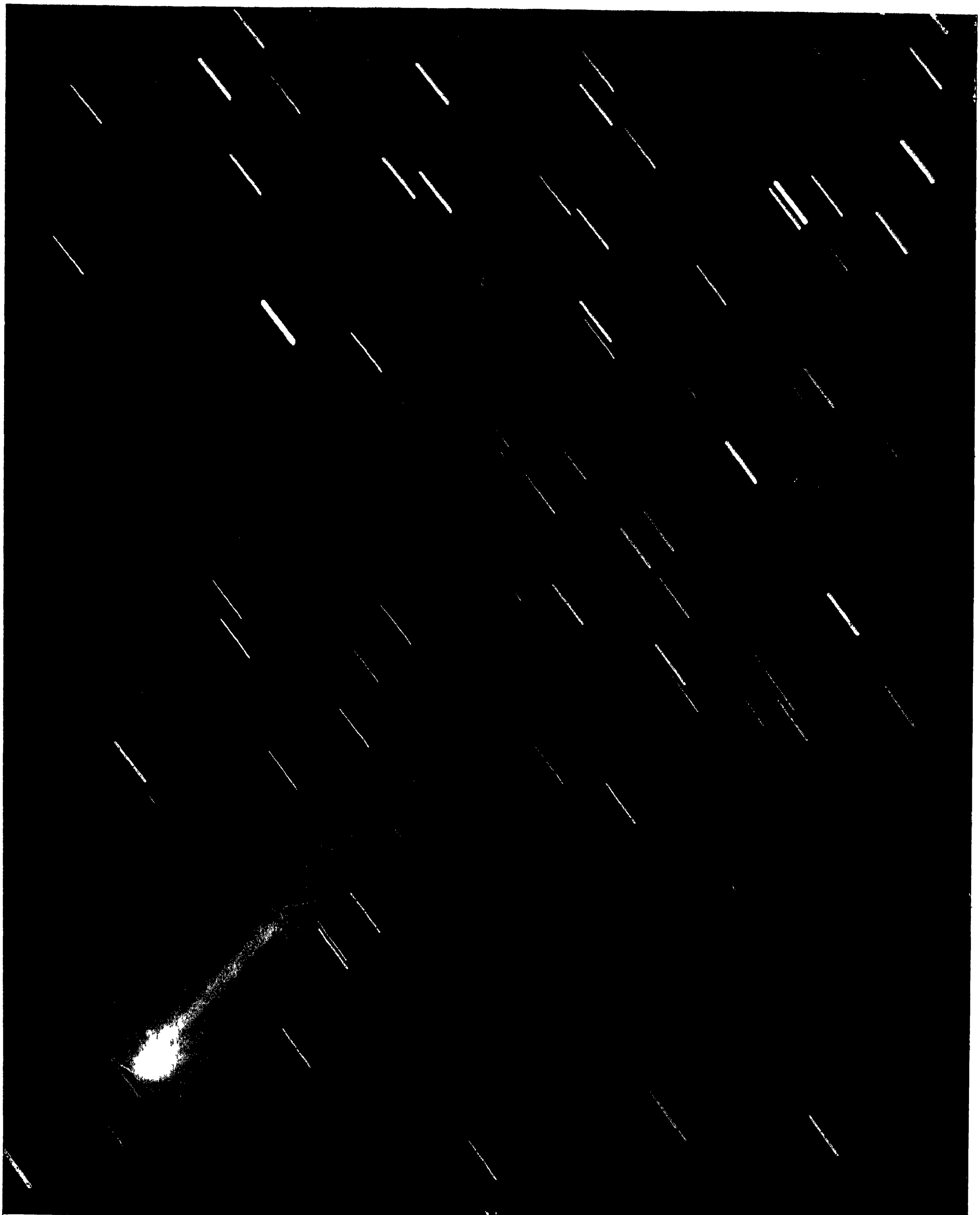


From "Knowledge" [*Lowell Observatory*

CHART OF THE LAST VIEWS OF HALLEY'S COMET, 1911, MAY

The positions shown are taken from photographs made at the Lowell Observatory They were made more than a year after the perihelion passage, and the Comet had become very faint It was, however, brighter after perihelion than before, owing to the excitation produced by the Sun The Comet will remain invisible till 1985

round the whole Cometary orbit, a length of many thousands of millions of miles The scattering is not uniform, but is much thicker near the Comet Hence the brilliant Leonid displays have recurred at thirty-three year intervals In view of this disintegration it is not surprising to find that the accompanying Comet has deteriorated rapidly There are grounds for believing that it is the same as a Comet seen in China in 1366, "its colour resembled that of a handful of meal, and it was nearly as large as a tow measure" In 1866 it was a feeble telescopic object, and could not be found at all in 1899



From "Knowledge"] [*By permission of the Astronomer Royal*

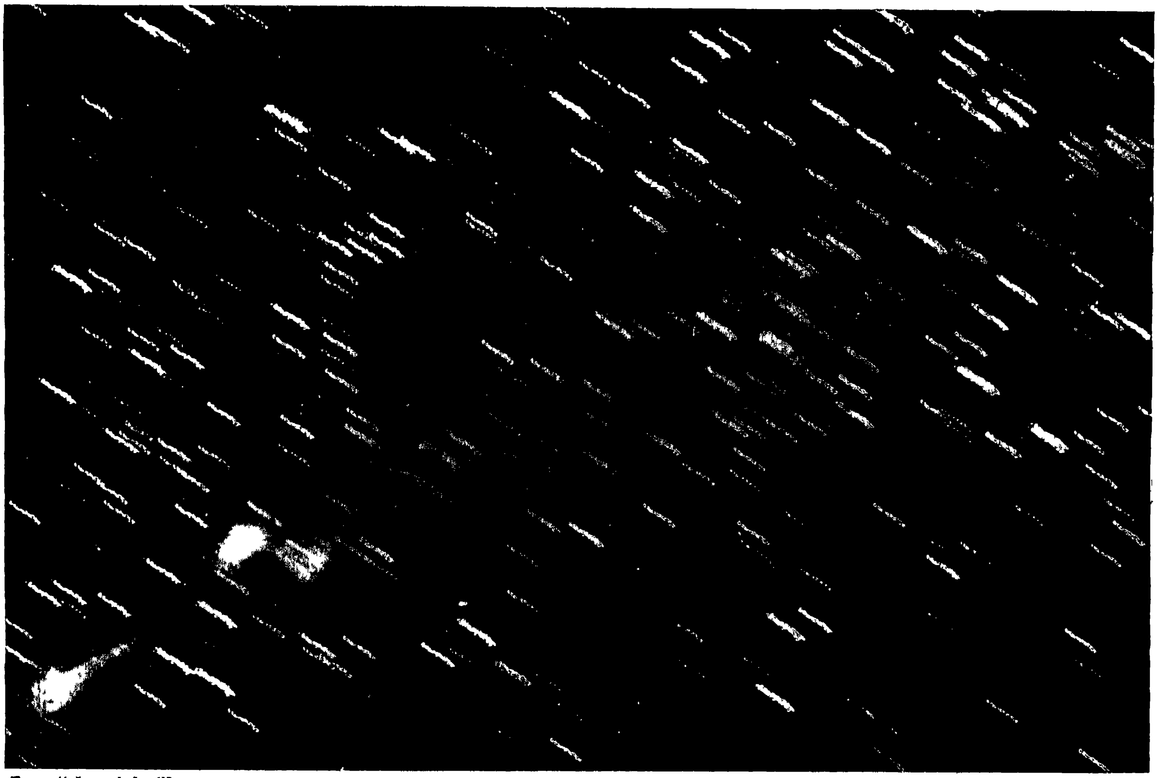
COMET "C," 1908 (MOREHOUSE), ON SEPTEMBER 29

The twisted aspect of many of the tail streamers will be noticed, also the appearance of the stars as lines, produced by the Comet's rapid motion

The Aquarids are also distributed round a considerable part of the orbit of Halley's Comet, but the dissolution of this body has not progressed so rapidly It is probably not quite such a fine object now as it was in 1066, but it still excited great enthusiasm in southern countries in 1910, so that it must have been a much more massive body to start with, or else the Leonid Comet is much older

Having discussed the manner of the slow dissolution of Comets, we may speculate a little concerning their origin Their close association with meteors has been proved, now the latter bodies are found to be very complex, some of them consist of iron, others contain nickel, tin, also silicates and other mineral compounds A considerable amount of hydrogen and other gases is found in them, which suggests an origin in the Sun, or giant planets, where alone in the Solar System hydrogen exists in a free state, on Earth it is only found in combination

A solar origin is naturally one of the first to be tested When we note that the orbit of the great

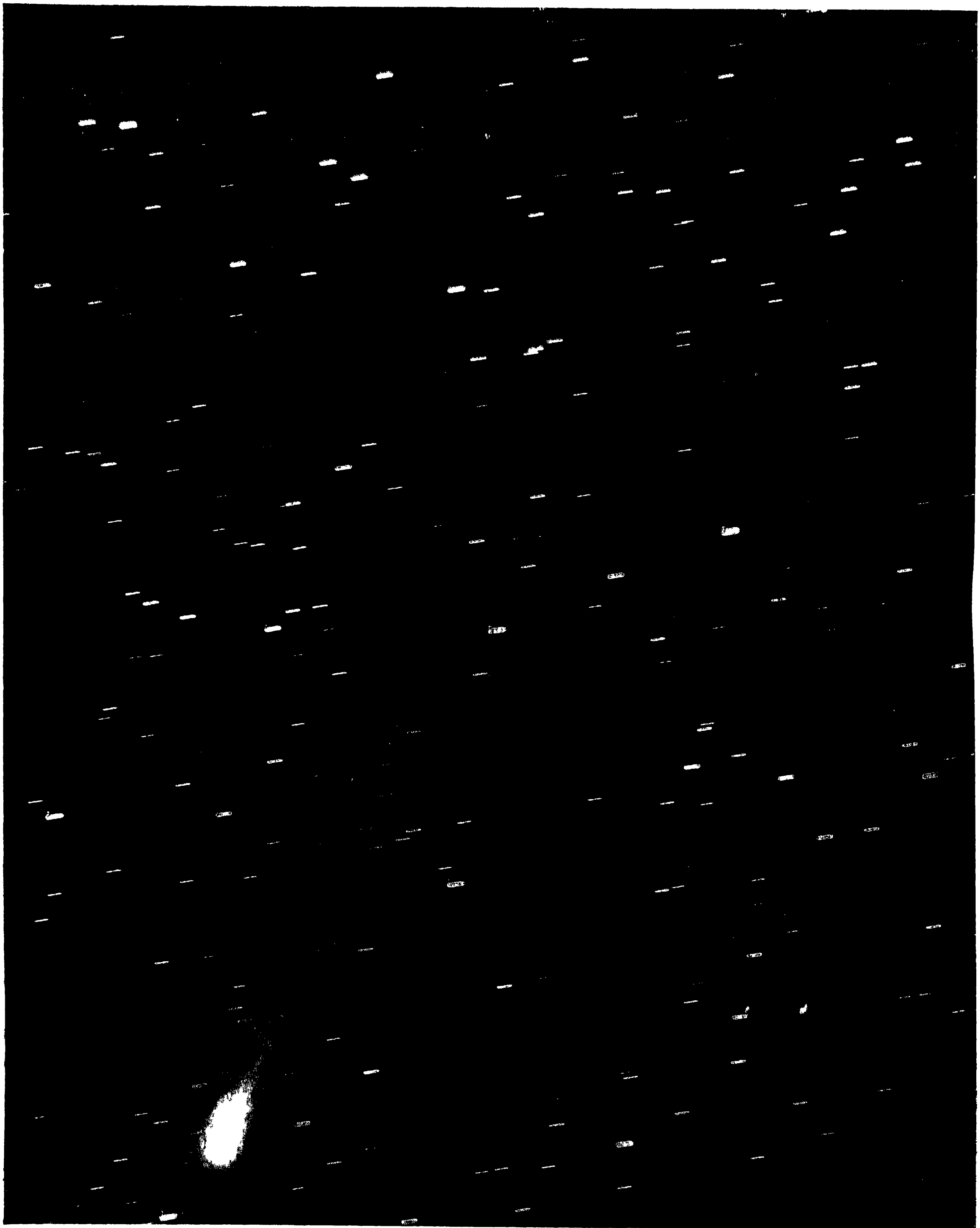


From "Knowledge"] *[Photo by E E Barnard*

COMET, 1908, III (MOREHOUSE) OCTOBER 15, 12m 57s

Morehouse's Comet showed very rapid changes in the structure of the tail It here seems to be discarding one tail and forming another Owing to the Comet's rapid motion the stars appear as lines

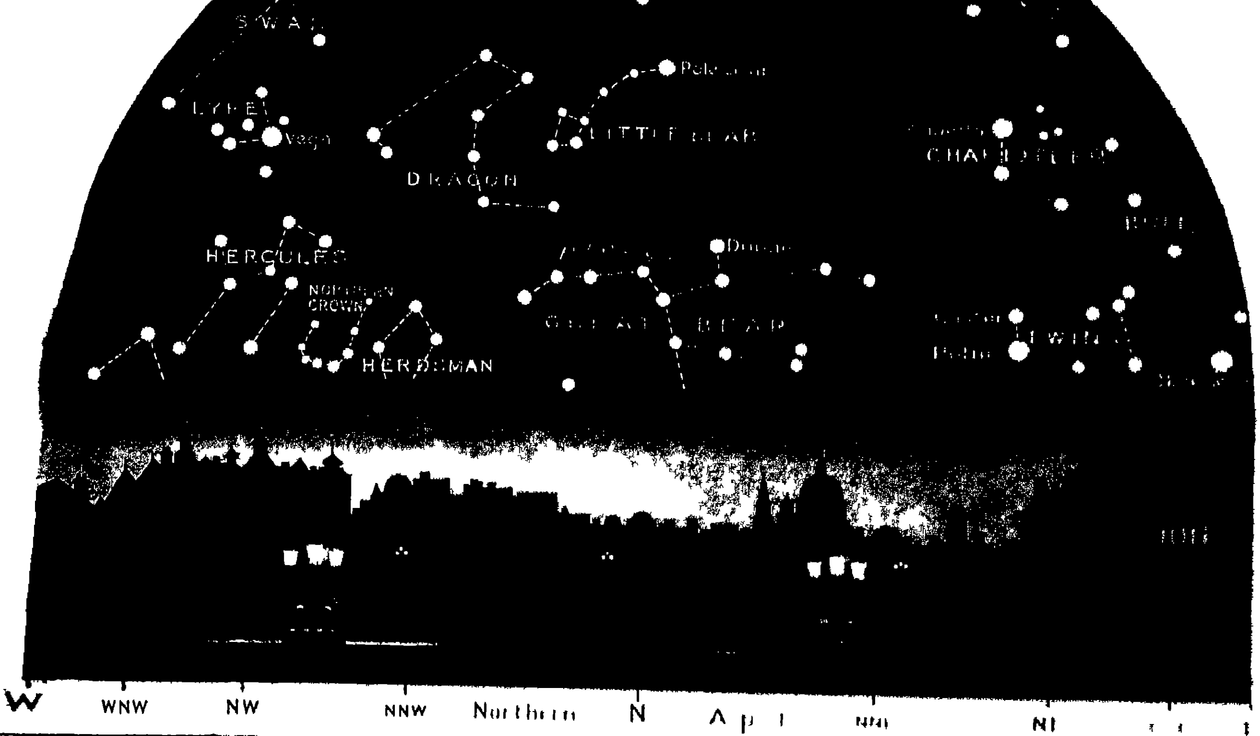
Comet of 1882 almost grazes the Sun's surface, there is a natural tendency to attribute a solar origin to it We know from the phenomena of the solar prominences that the Sun is continually erupting torrents of matter with very high speeds, a speed of 270 miles per second would suffice to send the matter round the Sun in a circular orbit, if it rose to 382 miles per second the orbit would be parabolic, while for any intermediate speed it would be elliptic By combining the observed speed of ascent of the prominence matter with the speed of approach or recession that is indicated by the shift of the lines in the spectrum, we conclude that speeds of this order are quite common, so that no difficulty arises on that account I feel rather more difficulty from the consideration that the meteoric masses that compose a Comet's head could not exist in the Sun in a solid state, the heat would suffice to vaporise them The materials would solidify in the cold of space, but as they would be under no

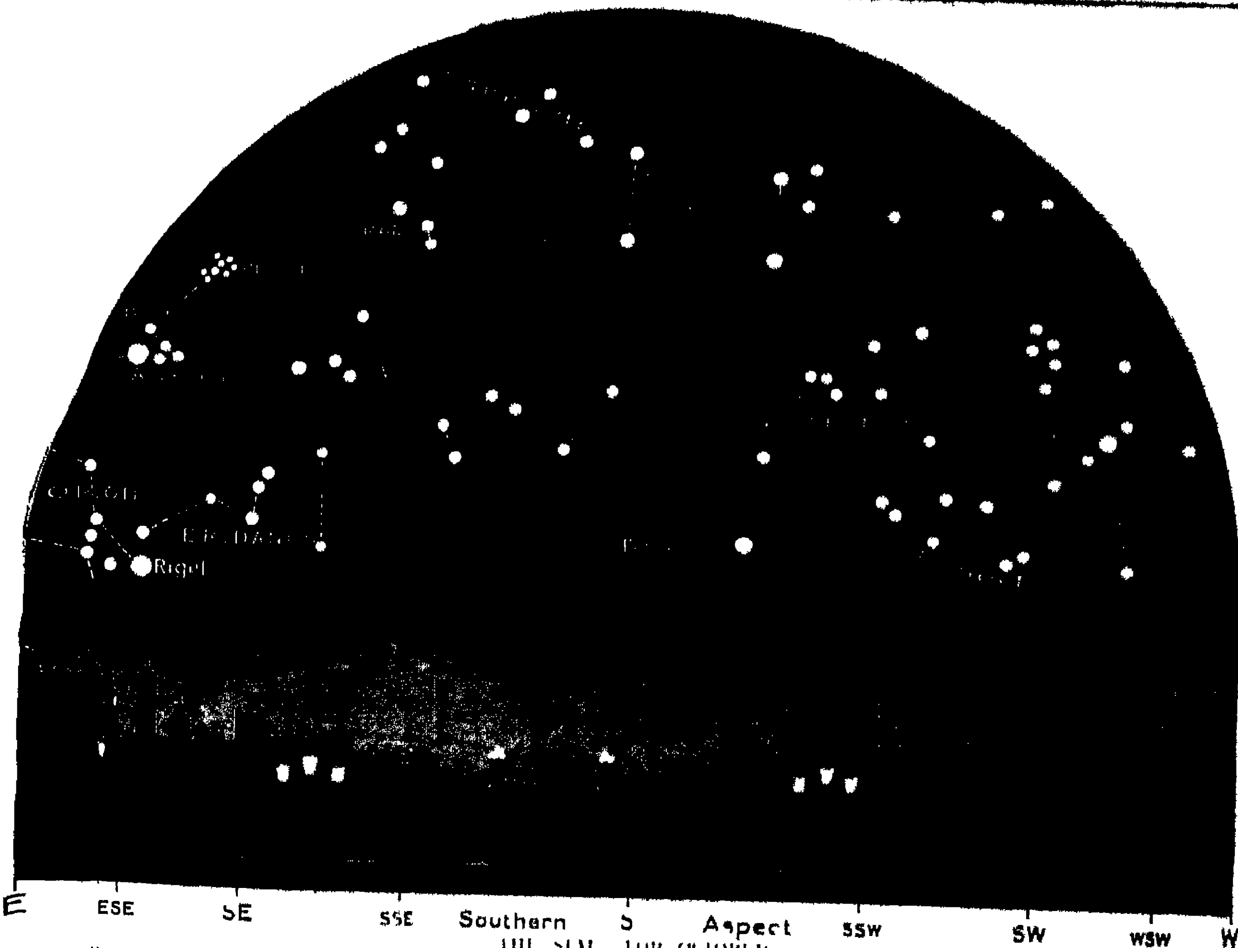


From Knowledge" [By permission of the Astronomer Roya

COMET "C," 1908 (MOREHOUSE), ON OCTOBER 27

This Comet, though inconspicuous to the eye, was full of interest in the camera The tail is here seen to consist of a number of divergent streamers, like Cheseaux's Comet of 1744





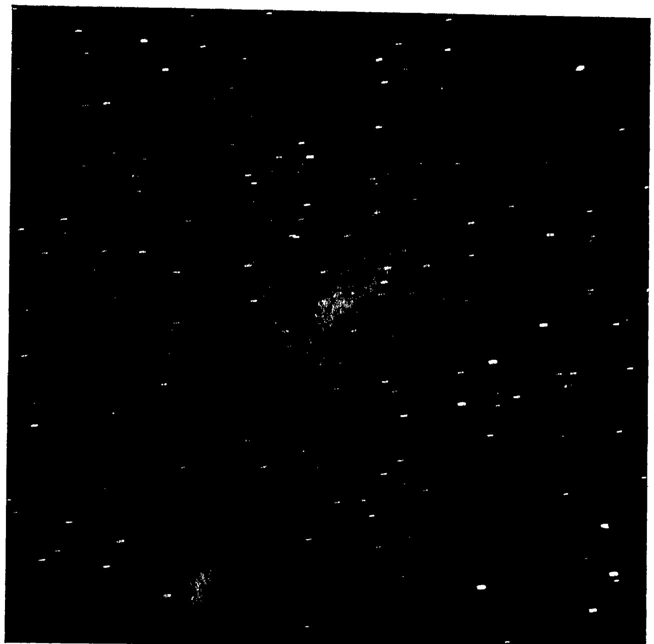
THE STAR[illegible] FOR OCTOBER

Our plate sh[illegible] the [illegible] of the [illegible] seen looking North and South from Westminster Bridge [illegible] but the position of the [illegible] will be practically the same for any place in the latitude of Great Britain.
The constellat[illegible] will appear [illegible] shown on October 1 at about 11.30 p.m. (Greenwich Mean Time)
11.0 p.m.
10.30 p.m.
10.0 p.m.
Each night the same [illegible] present [illegible] minute[illegible] earlier th[illegible] on the previous night.

pressure, I imagine that the resulting solid particles would be microscopically small, not of the size required to form reservoirs for a large amount of gas.

All objects ejected by the Sun would move in orbits that intersect the Sun, except in so far as their orbits are modified by planetary action. This latter might readily be large enough to change the orbit to one just outside the Sun (like those of the sun-grazing Comets of 1680, 1843, 1882, etc.). However, the great majority of known Comets have orbits whose least distance from the Sun is so large that we cannot imagine an origin for these by simple solar eruption.

We may, of course, carry our thoughts back to the planetesimal hypothesis, described on pages 80 to 82; the existence of Comets was there mentioned as strengthening the hypothesis. The question, however, arises: Can the Comets have existed for so long a period in view of the wastage that they undergo? According to the geologists the date of the approach of the other Sun must be put at least a thousand million years ago; in such an interval, even the Comets of longest period would have returned thousands of times, and I gravely doubt whether they could continue to be such compact bodies as they appear to be; I frankly admit that I have no plausible suggestion to offer for evading the difficulty; it is one of the numerous cases in Astronomy (the status of the spiral nebulæ is another) in which we must be content for the present to record observed facts and suggested interpretations, leaving full understanding to come at a later date, if at all.



From "Knowledge." *[Photo by Melotte and Davidson*

COMET, 1908, III (MOREHOUSE), OCTOBER 30, 7h 47m

This photograph well illustrates the "streaming hair" aspect from which the name "Comet" was given. It can be seen that the tail consists of divergent streamers with dark spaces between.

If we hesitate to postulate such a great age even for the Comets of long period, we may, I think, summarily dismiss the possibility of such an antiquity for the short-period ones, which have to suffer the oft-repeated disintegrating agencies of both Sun and planets. I have already noted that the effects of these destructive forces are quite manifest even in the short period over which observation extends; for the Jupiter family of Comets this interval is less than two centuries, yet it has witnessed the definite demise of Biela's Comet, and the probable demise of Brorsen's and others, which have failed to reappear at the times calculated. It looks, in fact, as if the life of a Comet of Jupiter's family is limited by a few centuries, or millenniums at most, instead of thousands of millions of years.

Before giving theories for the origin of the Comet families belonging to the giant planets, it is well to describe these families in somewhat more detail; that of Jupiter is much the largest, consisting of some fifty members; it is impossible to give an exact number, partly because new members are being added frequently (one very interesting member, the Comet Grigg-Skjellerup, was added in 1922) and partly because there are possibilities of identity among some of the members. The periods of revolution range from five years to nine years. I am excluding Encke's Comet, because it is doubtful whether it can be classed as a Jovian Comet. Its period is three and one-third years, and its most distant point is ninety million miles inside Jupiter's orbit, so that it does not experience very large perturbations at any time; the true members of the family are liable to pass very near Jupiter; in fact most of them have actually done so, and experienced great disturbances of their

orbits Some in fact have penetrated Jupiter's satellite system, in such cases Jupiter is taken as the controlling centre of the Comet's motion for the few weeks of close proximity, the Sun being regarded simply as a disturbing planet It will be noticed that the action of the Sun on Jupiter is taken into account in the tables of its motion, so all that we require to consider is the slight difference of the Sun's action on the Comet from that on the planet The more interesting members of this family will be described in detail later

Saturn has a family of only two members One of them was discovered by Tuttle in 1858, and bears his name, though it was found to be the same as one found by Méchain in 1790 It returns every thirteen and three-quarter years, and is due in 1926 The other was discovered by Peters in 1846, the period thirteen years four and a half months was calculated, but it has never been seen again

Uranus has likewise a family of two, one being Tempel's Comet of the November meteors,

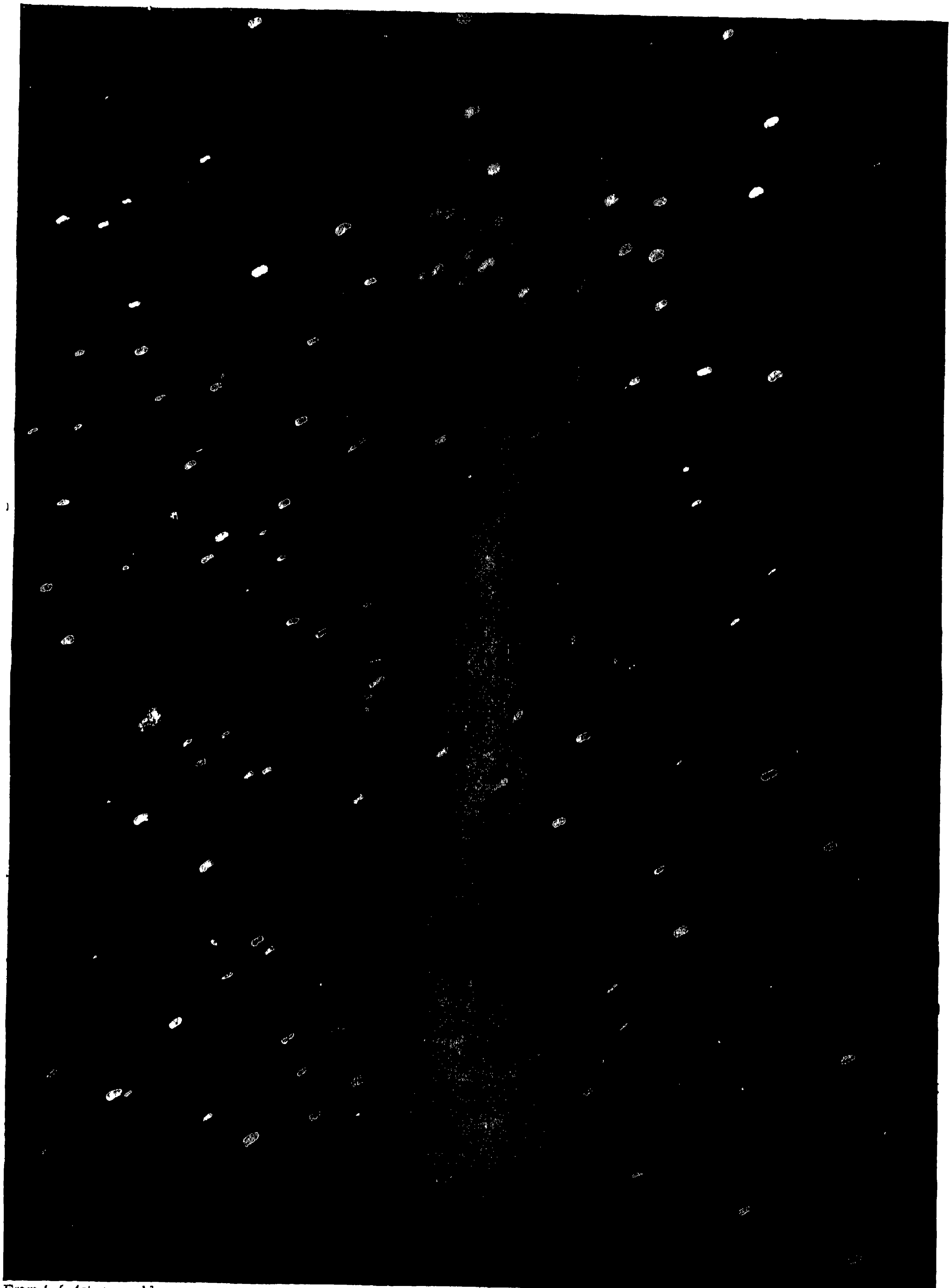
From "Knowledge"] [Photo by Metcalf

MOREHOUSE'S COMET, 1908, NOVEMBER 15

This picture, like several others, shows the tail split up into streamers, like the ribs of a fan, with dark spaces between The parabolic hood round the head will be noticed, also the twisted appearance of the main tail

mentioned on page 405, where its identity with the Comet of 1366 was stated to be probable The other is Stephan's Comet of 1867, found to have a period of forty years one month, but not seen again

Neptune's family is the most interesting of any of the four, since Halley's Comet belongs to it, this is the one really brilliant Comet whose appearances are capable of prediction Four other members of the family have been seen at a second apparition, these are (1) Pons's of 1812, recovered by Brooks in 1883, when it was an interesting object, Trépied made a drawing showing a large circular coma containing a spindle-shaped nucleus, also a parabolic hood on the sunward side, and a short tail, (2) Olbers's of 1815, recovered by Brooks in 1887, (3) Brorsen's of 1847, recovered by Metcalf in 1919, and (4) Westphal's of 1852, recovered by Delavan in 1913, it was at first fairly conspicuous and became just visible to the naked eye, with a tail three and a half degrees long, but it faded with



From 'L'Astronomie'] [By Professor Max Wolf

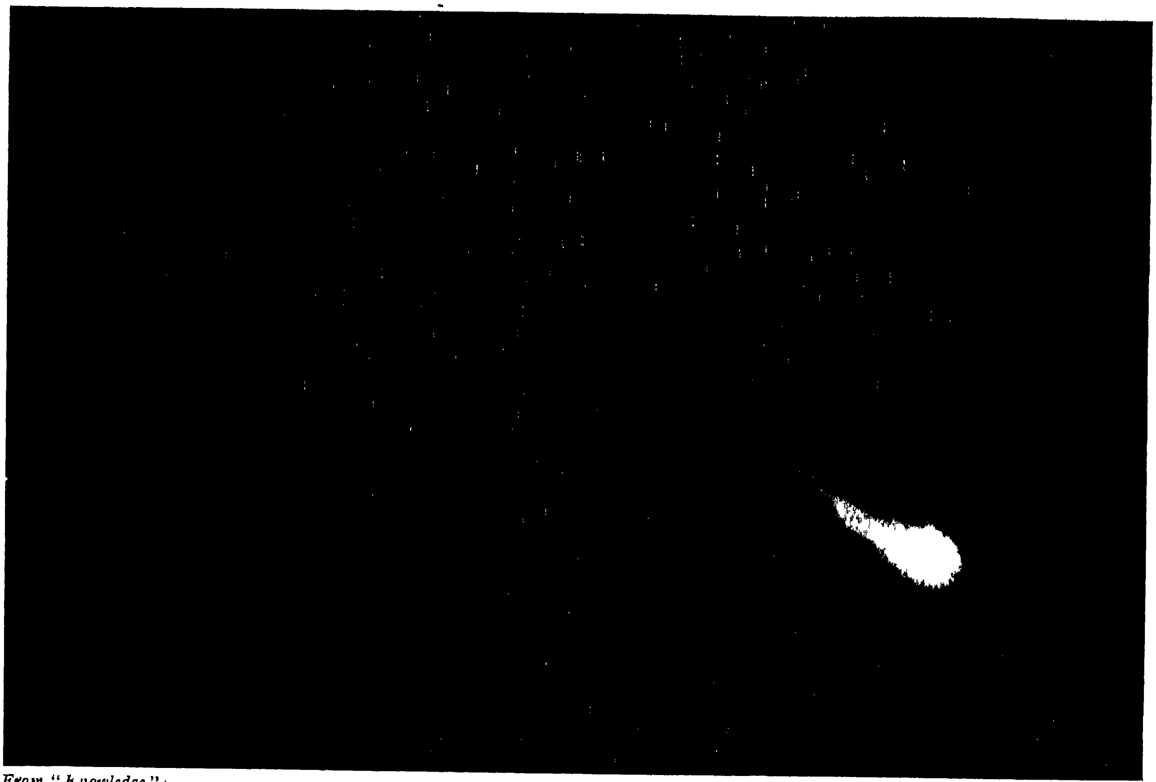
LARGE SCALE PHOTOGRAPH OF MOREHOUSE'S COMET, 1908, NOVEMBER 16

This photograph shows clearly the separate streamers of the tail, which spread out like a fan. We have to assume a repulsive force, from the head of the Comet, as well as from the Sun, to explain these lateral rays. The transparency of the tail is shown by the visibility of some star images in its brightest portion.

surprising rapidity, another member of the family, de Vico's of 1846, was expected to return in 1921, but has not yet been seen As the period is not certain within three years, it may yet be found There is a seventh Neptune Comet, discovered by Pons and Gambart in 1827 It was not at that time noted to be a short-period Comet, so no search was made for its return about 1890, a few years ago, Mr S Ogura of Japan rediscussed the orbit and found a period of about sixty-four years

Allusion has already been made on page 108 to the possible existence of other families that may indicate the existence of undiscovered planets beyond Neptune, the evidence is somewhat indefinite, but it may be of interest to give the list of the other Comets for which periods of less than 800 years have been found, noting that in all cases there is an uncertainty of at least two or three years, and the longer the period the greater the uncertainty

The periods of the Comets in any family are in the neighbourhood of half the planet's period,



From "Knowledge"] [Photo by Metcalf

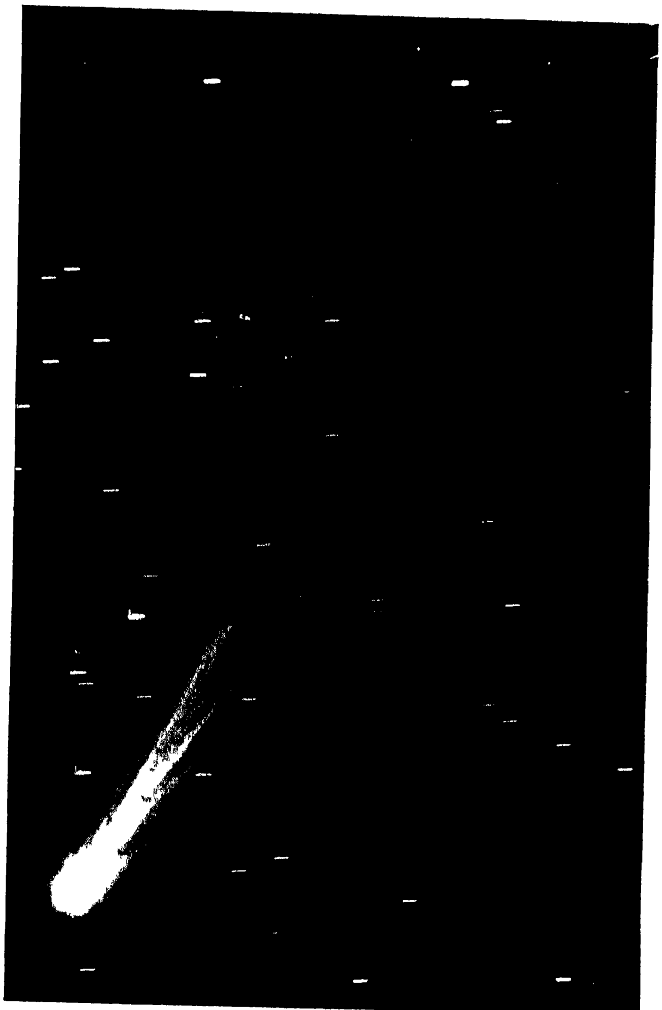
MOREHOUSE'S COMET, 1908, NOVEMBER 17

Very energetic processes must have been going on in the head of this Comet to produce the divergent tails and the complicated, ever changing aspect of the main tail The bright projection and arch in contact with the head of the Comet on its upper side are due to the presence of a bright star

or slightly less For each Comet the year of discovery, the name of the discoverer, and the period in years are given 1862, Tuttle, 120 years, 1889, Barnard, 128 years, 1917, Mellish, 189 years, 1857, Peters, 235 years, 1885, Brooks, 274 years, 1905, Giacobini, 297 years, 1874, Coggia, 306 years, 1840, Bremiker, 367 years, 1861, Thatcher, 415 years, 1861, Tebbutt, 409 years, 1898, Perrine, 417 years, 1793, Perny, 422 years, 1882, Great Comet, 772 years There is room for a suspicion of a planet with period a little under three centuries, and another of about nine centuries, with possibly one or two between, but the data are indefinite Professor George Forbes presented a paper to the Royal Astronomical Society in December 1908, in which he made the conjecture that a planet exists with period 1,000 years He suggested that the Comet of 1556, supposed to be identical with that of 1264, passed near it about 1702, and was split into four fragments, which were the bright

Comets of 1843, 1880, 1882, 1887 He gives a list of seven Comets that he supposes to have passed near the planet, and been greatly perturbed He is obliged to give the planet the very large inclination of fifty-three degrees, the number of near approaches in the case of such a distant planet seems to me beyond what probability suggests, but the suggestion is sufficiently interesting to justify reference to it Professor W H Pickering has also drawn up a list of several hypothetical planets, based partly on Comet statistics In any case, whether planets are there or not, the Comets themselves demonstrate that the Sun's domain is far vaster than we should judge by considering the planets alone, it is demonstrably certain that the great majority of the long-period Comets recede to more than a thousand times the Earth's distance from the Sun, or thirty times the distance of Neptune At that distance the light and heat would be only a millionth of that which we receive, the Sun would, however, still appear ten thousand times as bright as Sirius, so that one would have to go much farther to get beyond the region where he reigns as monarch

Taking Comets as a whole, the number of those that go round their orbits backwards, *i e*, in the reverse direction to the planets, is very nearly equal to that of the forward-movers, but when we consider those of short and moderate periods, there is a great preponderance of direct motion There is not a single exception to this in the families of Jupiter and Saturn, Uranus has one retrograde Comet, Tempel's of the November meteors, Neptune has two, Halley's and that of 1827 The only other retrograde Comet with a period under five centuries is Tuttle's, associated with the August meteors Retrograde Comets give more brilliant meteor showers, their motion being opposed to that of the Earth, they traverse our atmosphere at a higher speed, and are raised to a higher temperature



From "Knowledge"] [Photo by Melotte and Davidson

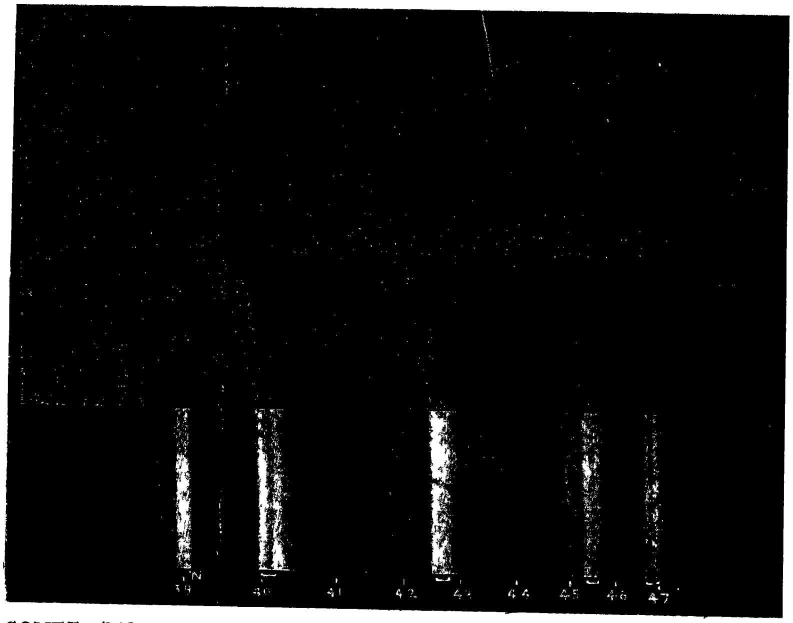
COMET, 1908, III (MOREHOUSE), NOVEMBER 19, 6h 4m

There are evidently several different sheaves in the main tail, the result of separate emissions The short lateral tails are well shown

There are two theories to account for the existence of the Comet-families of the giant planets, the one usually accepted is that these Comets were formerly long-period ones, which happened to pass near one of the planets, and had their velocity reduced and period shortened Since the Jupiter family is by far the largest, and since the orbits of its members are much better known than those of the others (with a few exceptions), it is suitable to take it as the basis for discussing this theory

The velocity of a Comet passing Jupiter's orbit with parabolic motion is eleven and a half miles per second, on the other hand the velocity of a Jupiter Comet when crossing his orbit is only about five and a half miles a second Thus Jupiter has to deprive the parabolic Comet of about half of its

speed in order to convert it into a member of his Comet family, the orbital speed of Jupiter's fourth satellite, Callisto, happens to be about five miles per second; I am considerably understating the case when I say that the Comet would have to pass at least as close to Jupiter as that satellite, in order to suffer this reduction of speed; it can readily be shown that only about one Comet in half a million would pass within that distance of Jupiter. The proof is so easy that some readers may like to have it: the angular distance of Callisto from Jupiter as seen from the Sun is nine minutes, or 0.15 degrees; draw a circle round Jupiter with this radius, its area in square degrees is 3.142 multiplied by the square of 0.15, the product being 0.0707. Now the whole sphere contains 41,253 square degrees, and 0.0707 goes into this 583,000 times. We have already noted in this chapter that on the average some three Comets approach the Sun each year; it would therefore take almost 200,000 years for one new member to be added to the Jupiter family by capture; this is clearly nothing like enough to balance the wastage, of which we have given evidence, and keep up the supply. The upholders of the capture theory are conscious of the difficulty, and seek to get round it by supposing that Jupiter captures Comets not at a single swoop, but by successive stages, taking a little off the velocity each time. As I said above, I have notably understated my case, for when a Comet passes close to Jupiter its speed is generally being increased for part of the time, and diminished for another part; it is only the difference of the two actions that is finally effective; and this is as likely to be in one direction as the other; a succession of near approaches, all of which produced diminution of speed, would very seldom happen. Another objection that I see to the theory of successive diminutions of speed is that on that view there ought to be Comets with a wide range of period, all passing close to Jupiter's orbit; we do not find this in fact; there is a definite limit of period, the largest periods of members of the family being eight and a half years; we find nothing between this and the thirteen and a half years belonging to Saturn's family. And it should be noted that the short period does not in any way make for stability; if it did, we might look on its prevalence as a survival of the fittest; but it merely gives additional opportunity for repeated large disturbances by Jupiter.



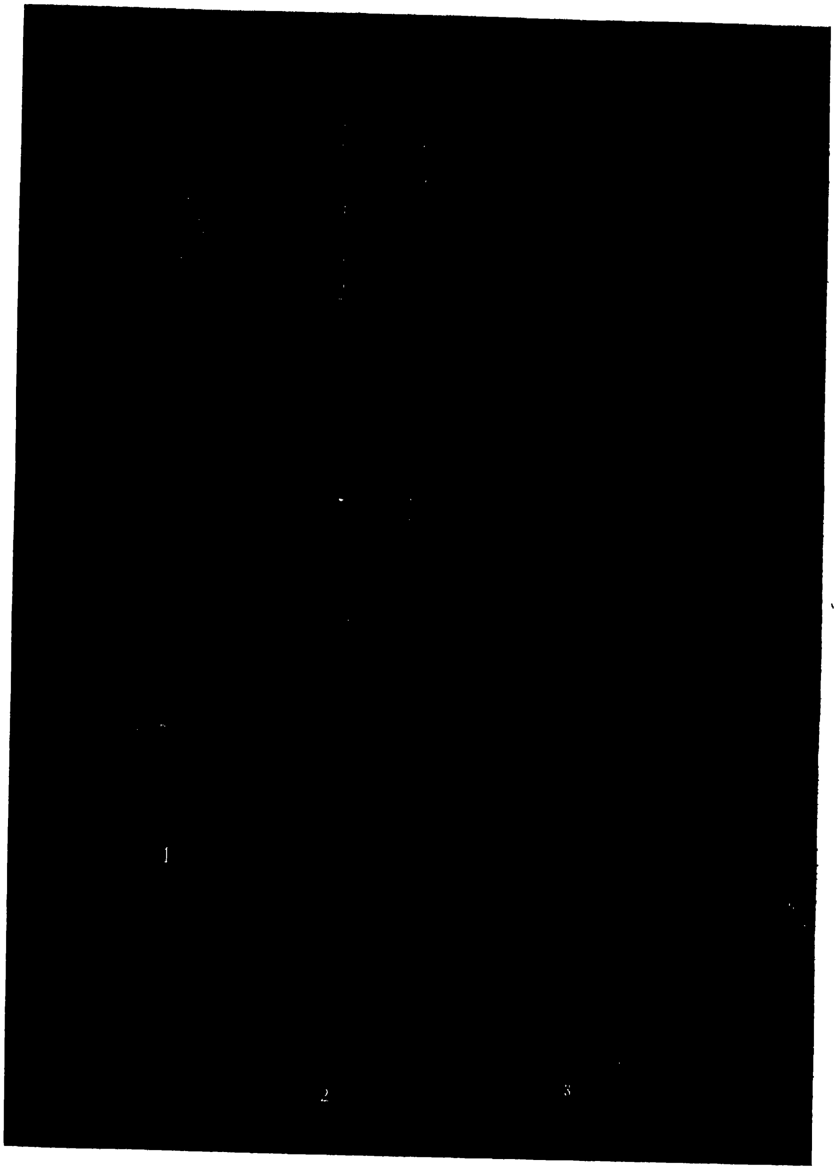
COMET (MOREHOUSE), 1909, MARCH 20: OBJECTIVE SPECTROGRAM ABOVE, BY PROFESSOR CURTIS, SANTIAGO; SPECTROGRAM OF CARBON MONOXIDE BELOW, BY PROFESSOR A. FOWLER

The objective prism is very useful for finding the spectra of faint objects like Comets' tails. The close agreement of the bright bands in the orbitary spectrum with those of carbon monoxide was detected by Professor A. Fowler

The fact that the members of the Jupiter family have direct motion in all cases appears to give a fatal blow to the capture theory. Practically as many Comets would approach the planet with retrograde motion as with direct; there is, indeed, the point that those travelling in the same direction as the planet would remain longer in its neighbourhood, and so have more time to be perturbed, which has some weight; but that out of some fifty Comets there is not a single retrograde one is too remarkable a fact to pass over, and it clearly suggests that Jupiter played a different part from that of a mere enslaver, and was concerned with the origin of these bodies in a more intimate manner

Many of the considerations that I have brought forward were stated by Mr R A Proctor some fifty years ago, they have therefore been quite accessible to astronomers, who nevertheless have been as a rule quite unaffected by them, so that it is time to state them afresh The consideration that the life of a short-period Comet is limited by the rapid wastage to which it is subject by the joint action of the Sun and Jupiter, was not, I think, so fully realised when Proctor wrote as it is now It serves further to invalidate the capture theory, since it prevents our assigning to these bodies such extended lives as that theory demands

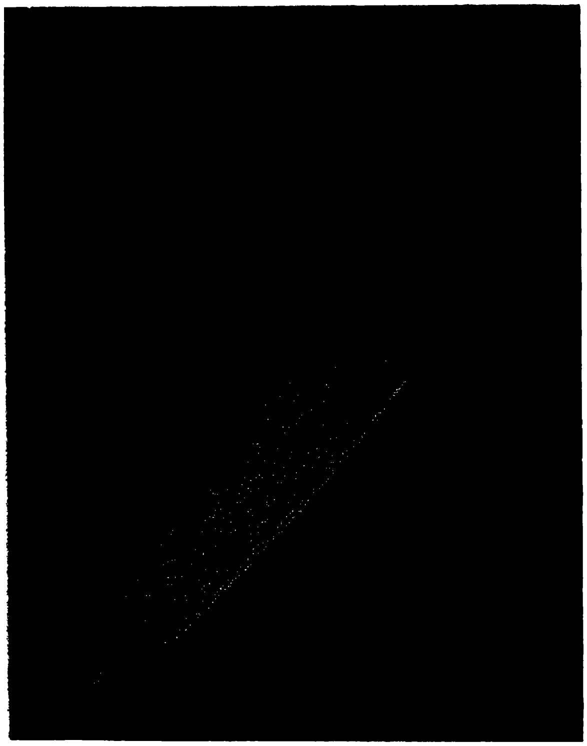
The theory that Proctor put forward as an alternative seems to be the only alternative to the capture theory, it is that the giant planets are themselves the parents of their Comet families, this view does not seem to me to be unreasonable, we have a great amount of evidence as to the energy of the processes that are going on in Jupiter and Saturn, and by inference in Uranus and Neptune likewise, though distance in their case hinders direct observation, even on our own Earth we have had some striking demonstrations of the power of volcanic energy It is well worth while to study the Royal Society's Report on the eruption of Krakatoa in 1883 The sounds of the explosions were heard 3,000 miles away, the great sea waves travelled for thousands of miles, while the air-waves were traced several times round the world Such a huge volume of dust was blown to the highest regions of the atmosphere that it was carried to every part of the Earth and caused remarkable sunset glows for more than a year We are entitled to expect much vaster convulsions in Jupiter, which outweighs the Earth 300 times, and seems to be in a much hotter state, judging by the very deep envelope of vapours that surrounds it and the



FORMS OF COMETS

1 Comet of 1577 (Cornelius Gemma) 2 Comet of 1680 (J C Sturm) 3 Comet of 1769 The first picture shows the sword-like aspect so often ascribed to early Comets The tail of the 1680 Comet was remarkably straight That of 1769 shows two faint divergent tails These are often seen on photographs.

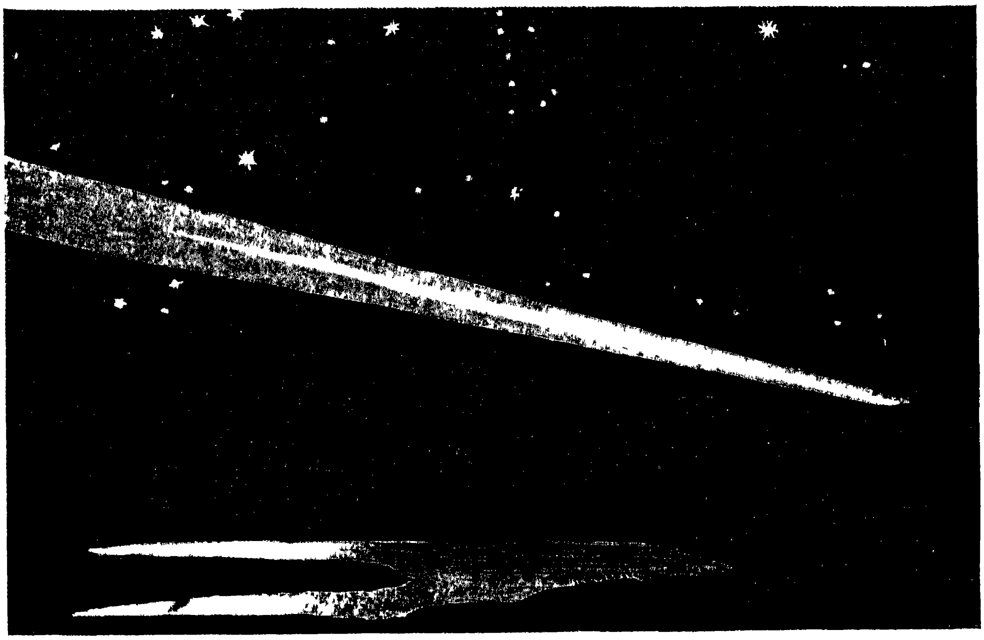
rapid changes, on an enormous scale, that are constantly going on In particular I would ask the reader to turn to page 28, where the great Red Spot is pictured, I do not in the least endorse the suggestion that is there hinted at, that this may be a stage in the formation of a new satellite, but when we consider the stupendous outpouring of energy that the spot indicated (its area was as large as the whole surface of the Earth) it seems not at all unreasonable to imagine that a sufficient amount of solid matter and gas may have been ejected into space to form a new small Comet One or two births per century would suffice to balance the wastage, and there are some earlier records of markings resembling the Red Spot On Saturn we can point to the remarkable white spot that appeared in the temperate zones some years ago, it gave the very long period of rotation of ten hours thirty-seven minutes which seems to show that the eruption causing it came from a great depth, where the speed of rotation would be slower, owing to the smaller circle to be described It seems likely that Saturn has other Comets besides the two that we know, some might have orbits that did not come near enough for us to see them More than one observer has noticed that Uranus and Neptune show at times a variation of light in ten and three-quarters and eight hours respectively, this doubtless indicates some large marking on their surface carried round by the planet's rotation, so that here also we have some evidence of disturbances



THE GREAT COMET OF 1811
A magnificent Comet marked the year of Napoleon's Russian campaign It was discovered by Flaugergues, and observed for seventeen months Its period is about 3,000 years The famous "Comet Port" dates from 1811

I shall now discuss the speed of ejection that would be necessary to expel matter from each of the giant planets This may be taken with sufficient accuracy as the parabolic speed at the surface of each, supposing that its attraction is the only force acting The speed in miles per second is thirty-seven and a half for Jupiter twenty-two and a half for Saturn, thirteen and a quarter for Uranus, thirteen and three-quarters for Neptune These speeds may appear improbably high, they undoubtedly enormously exceed any speeds that we observe in terrestrial eruptions, but observation indicates that the phenomena occurring there are on a much grander scale than here, and the improbabilities seem to me decidedly less than those involved in the capture theory The ejection theory also explains why we find no retrograde orbits in the Jupiter family, while we find a few in the case of the outer planets Jupiter's orbital speed exceeds eight miles per second, we should need to reverse this, and to give a speed of some miles a second in the other direction The total speed at Jupiter's surface would come up to fifty miles per second, this then would seem to be a speed that is not actually attained On the other hand, the two outer planets have orbital speeds about half that of Jupiter, and the ejection speed given above is only one-third of his, so that retrograde motion becomes possible

When Proctor postulated the planetary origin of these Comets he pictured their birth as having occurred in a remote past, when the planets were more sunlike than they are to-day To me such a long life of these bodies in a cometary form appears quite unlikely, and I conclude that if the planetary origin is true the birth of short-period Comets is still going on. Le Verrier conjectured

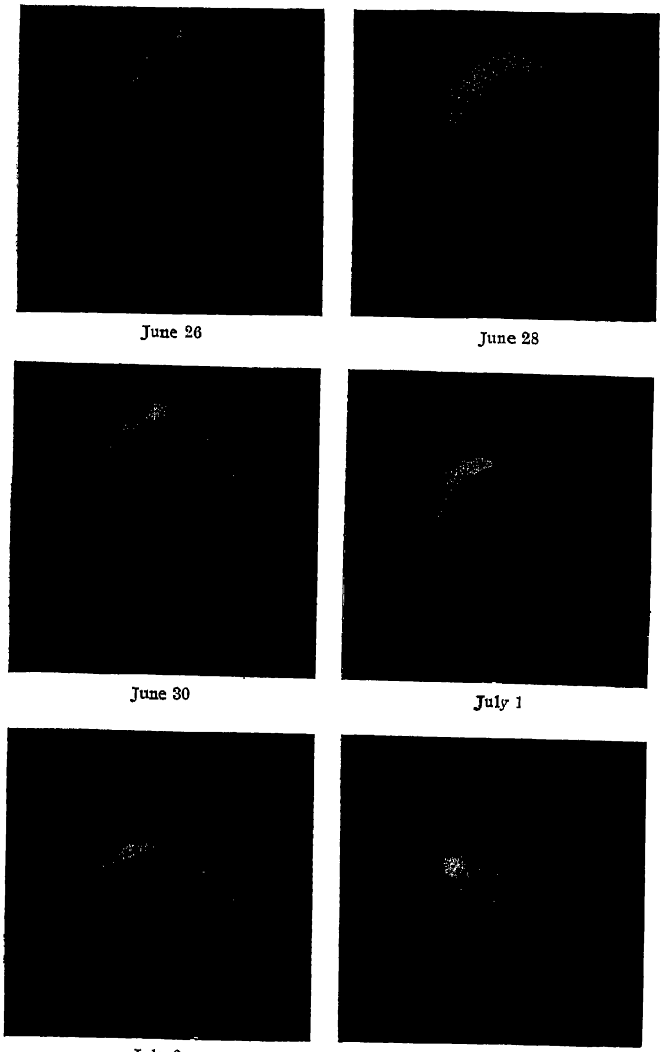


THE GREAT COMET OF 1843, MARCH 17 (AS SEEN FROM BLACKHEATH, KENT)
This picture shows well the aspect of the long straight tails of the Sun grazing Comets, "running like a road through the constellations," as Aristotle expresses it The Belt of Orion and Rigel are shown high left, Lepus, the Hare, is under them

DONATI'S COMET, 1858, OCTOBER 5 (PAPE)
The beautiful curved main tail is well shown It has a large faint extension to the right, which is not shown in all the drawings

(this is the correct word to use, though many people say he proved it) that Uranus captured the Comet of the Leonid meteors in A D 126 On the alternative theory this would be the date of its ejection from Uranus, I incline to think that a longer interval is required to effect the scattering of the meteors round the entire orbit, which is proved by the annual appearance of some of them

Neptune would appear to be in a condition favourable for the ejection of large Comets, since two members of his family (Halley and Pons-Brooks) are much finer than any of the Jovian family This supports Professor Lowell's view that the development of the giant planets started from the centre outwards, which would explain why the two outer ones, though so much smaller, appear to be in a similar physical condition to Jupiter and Saturn



THE COMET OF 1860, III (CAPPELLETTI AND ROSA)
This picture illustrates the fountain-like jets issuing from the head, and curving round into the tail under the influence of the solar repulsive force

The two outer planets, though the parents of their families, are no longer their controllers Jupiter and Saturn have usurped this rôle, for the double reason of superior mass and of the fact that fairly close approaches to them are much more frequent than they are with the parent planets The effect of these disturbances has been to shift the orbits away from those of the parent planets, so that close approaches cannot now take place, thus while Jupiter can alter the period of Halley's Comet by two years and Saturn by 100 days, the efforts of Uranus and Neptune are limited to a change of a week

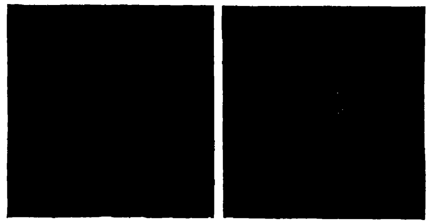
Some people, noticing that the inclination of de Vico's Comet is eighty-five degrees, have drawn the conclusion that its major axis is inclined at this angle, and that it never could have had any connection with Neptune, this is a mistake, the inclination of its major axis is only some seventeen degrees, so we have only to go back a few thousand years to find its orbit intersecting that of Neptune

This chapter began with a study of some particular Comets, having now given a sketch of what is known or conjectured as to their nature and origin I return to the special description of particular Comets

The great Comet of 1811 claims a high place, from its long visibility—seventeen months—and from the fact that it attained great brilliancy although its nearest point to the Sun lay outside the orbit of the Earth It was discovered by Flaugergues in March 1811, and reached its full splendour seven months later, when its tail was 100 million miles long, it had a large round head, with an almost stellar nucleus, its period is close to 3,000 years, but no record of any previous return can be found

It is associated with Napoleon's Russian campaign, and also with a remarkable vintage in Portugal, popular fancy ascribed this to the Comet, and "Comet port" figured in catalogues until the 'eighties

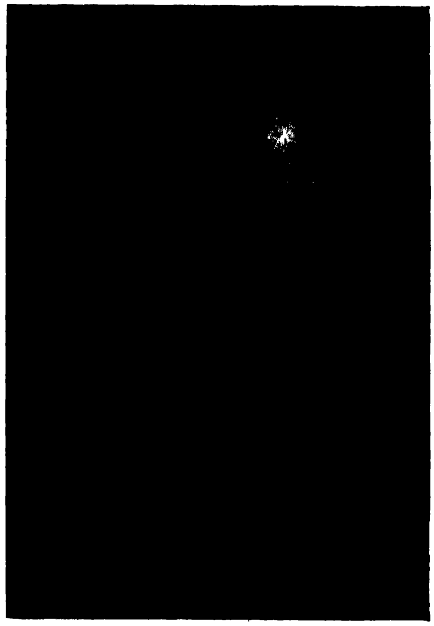
Leaving for the moment the 1835 apparition of Halley's Comet, the next grand visitor was that of 1843, it is convenient to describe this in conjunction with those of 1880, 1882, 1887, as they had probably a common origin, this is the family of Sun-grazing Comets, their nuclei passed within 400,000 miles of his surface, and the cometic envelopes must have actually brushed the Sun An enormous sunspot, with intense magnetic disturbances, occurred shortly after the passage of the 1882 Comet, which Proctor thought was a result of the graze The speed of these Comets when near the Sun was 300 miles per second, and they swept out eight-ninths of the 360 degrees of their orbit in a day, while the remaining ninth requires several centuries These Comets were so bright when near the Sun that they could be seen at noon with the naked eye Their tails were long and straight (*see* picture, page 417), and their length shortly after perihelion proved the intensity of the repulsive force To quote Sir J Herschel "Its tail, whose direction was reversed, and which could not possibly be the same tail that it had before had already lengthened to about ninety millions of miles, so that it must have been shot out with immense force in a direction from the Sun, a force far greater than that with which the Sun controlled the head of the Comet" As regards the heat which these Comets experienced when near the Sun, I quote Sir John again "Imagine a glare 25,600 times fiercer than that of an equatorial sunshine at noonday In such a heat there is no solid substance we know of which would not run like water—boil—and be converted into smoke or vapour" The successful photographs of the Comet of 1882 obtained at the Cape, and the part they played in leading to the great photographic star-map, were described on pages 50–53



TELESCOPIC COMETS

Without nucleus With a nucleus

When first discovered Comets seldom have tails They may or may not have a central nucleus



RORDAME QUÉNISSET COMET, 1893

While the "'Nineties" produced no brilliant naked-eye Comet, there were several of telescopic interest This one was discovered independently by Rordame (America) and Quénisset (France)

The Comet of 1680 was another sun-grazer, it is interesting as being one of the first whose orbit was deduced by gravitational methods The Comet of 1668, and a remarkable one in 371 B C, described by Aristotle as "Running like a road through the constellations," probably belong to this class but the observations are not precise enough to determine the orbits with accuracy

Donati's Comet of 1858 made a great sensation, he discovered it on June 2, when it had no tail and looked simply a circular mist, the tail began to develop in mid-August, and by the end of September, when the Comet was near both Sun and Earth, it appeared as a splendid scimitar, with two narrow straight rays that must have been projected at a greater speed than the main tail An interesting feature was the passing of the Comet over Arcturus (*see* page 105), the star shone undimmed through the obstacle,

DONATI'S COMET

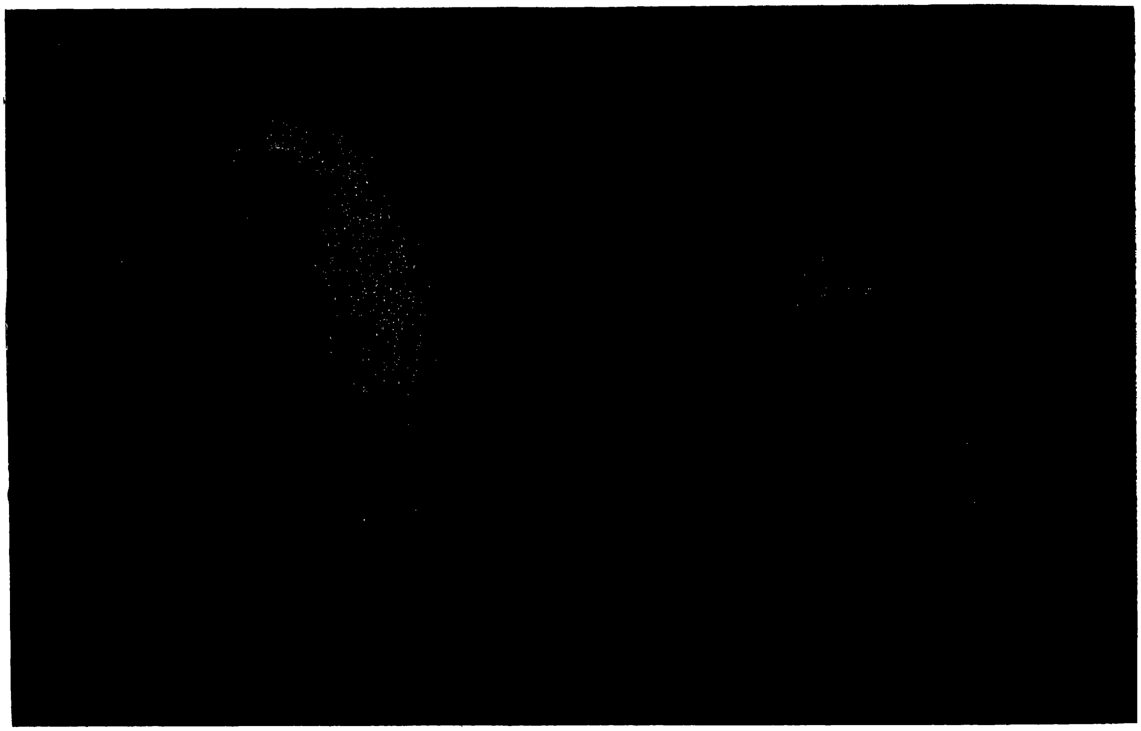
A very noted Comet with a tail curved like a scimitar It was at its brightest in October, 1858

in a few cases of stars passing behind Comets a slight loss of light has been suspected, also a slight shift of the star through refraction by the gases in the head, the amount has never exceeded a second of arc

The Comet of 1861 is interesting because the Earth passed through its tail, as it also did through that of Halley in 1910 In neither case did we suffer any inconvenience, but a curious auroral glare was noticed in 1861 When the tail was close to the Earth it looked like a widely open fan (*see* page 421), this was an effect of perspective The drawings made by Professor Barnard of the tail of Halley's Comet show a similar perspective effect (page 401) The proximity caused the extraordinary length of that tail, which reached 140 degrees, the longest tail ever seen as regards angle, though not in miles

Wells's Comet of 1882, which passed within five and a half million miles of the Sun, was at that time visible in daylight (this is the rule for all such near approaches) It had a pronounced yellow colour,

1 2

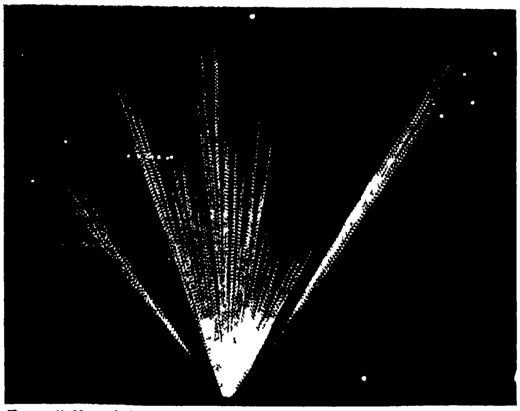


HEADS AND TAILS OF COMETS

1 Donati's Comet, 1858, September 29 (G P Bond) 2 Comet of 1861, July 2 (Warren De La Rue)
Nowadays we trust to photography for cometary detail, but before 1881 this was impossible Both the above Comets showed much interesting detail round the head, which is only explicable on the assumption that both the Sun and the head are concerned in the expulsion of the tail matter

which the spectroscope explained by showing the bright yellow line of sodium, a substance very widely distributed on earth, and well known as one of the constituents of common salt It is probably present in most Comets, but does not make its presence known except in near approaches to the Sun In this connection it is well to state that Comets are not at a high temperature when at the Earth's distance from the Sun, Comet panic-makers, a race that is unhappily not yet extinct, always picture them as wrapped in flames, but the glow of their gases is probably akin to that produced in vacuum tubes by electrical excitement The passage of the Earth through Comets' tails in 1861 and 1910 did nobody any harm, even collision with the head would probably involve nothing worse than a severe meteoric bombardment

The other bright Comets between 1882 and the present time are sufficiently described in the legends



From "Knowledge"] [*After R A Proctor*

THE GREAT COMET OF 1861

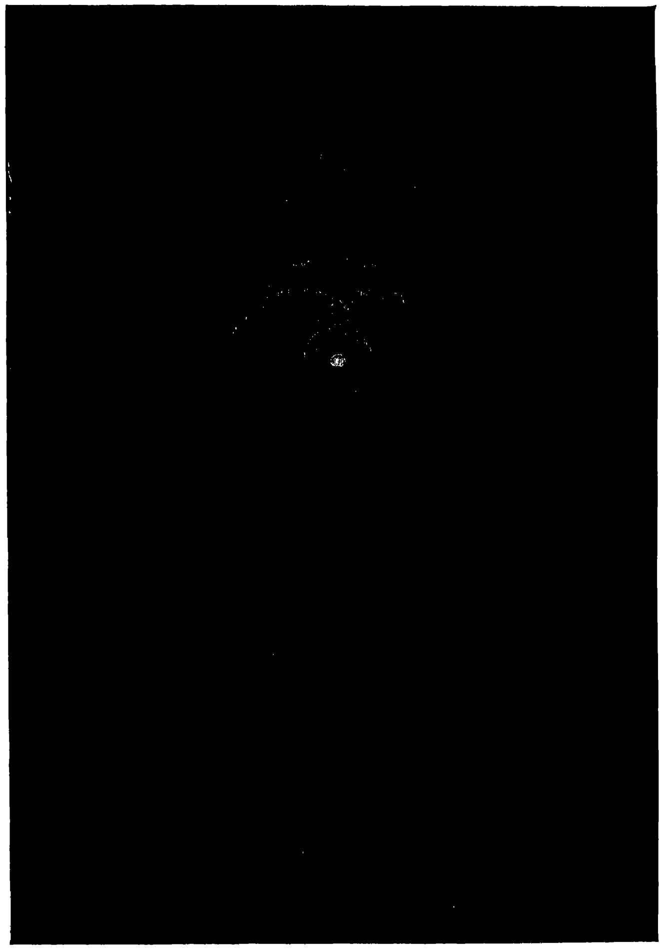
When this picture was made the tail was very near the Earth (which actually passed through it) The wide opening of the rays is an effect of perspective The "W" of Cassiopeia is high right, the Pole Star at the top

under the pictures I therefore proceed to give some further notes on Halley's Comet, in continuation of those at the beginning of the chapter A complete list of the dates of its return to perihelion will probably be useful for reference The earlier dates are uncertain by many days, the later ones are known to a small fraction of a day B C 240, May 15, 163, May 20, 87, August 15, 12, October 8, A D 66, January 26, 141, March 25, 218, April 6, 295, April 7, 374, February 13, 451, July 3, 530, November 15, 607, March 26, 684, November 26, 760, June 10, 837, February 25, 912, July 19, 989, September 2, 1066, March 25, 1145, April 19, 1222, September 10, 1301, October 22 7, 1378, November 8 8, 1456, June 8 2, 1531, August 25 8, 1607, October 26 9, 1682, September 14 8, 1759, March 12 6, 1835, November 15 9, 1910, April 19 7, 1986, about February

The return of B C 163 is the only one of these for which definite observations are not extant We have, however, the reference in Pingre that in that year (T Gracchus and M Inventius being consuls) "the Sun was seen at night" at Capua and Pisaurus This expression is also used for the Comet of Mithridates, and appears to denote an object of great brilliancy

The return of B C 12 is of interest from its occurrence within four or five years of the birth of Our Lord Some people have tried to make it the Star of the Magi, but it appears to be impossible to push the date of the Nativity so far back This appearance was followed in China in very minute detail, the course was through the Twins, Lion, Herdsman, Serpent, Scorpion, its motion at first being rapid owing to proximity to the Earth Dr Hind concluded that its orbit must then have been much closer to the ecliptic than it is now He gave the inclination as ten degrees, it is now eighteen degrees

The return of A D 66 is probably the sword of fire mentioned by Josephus as suspended over Jerusalem shortly before its siege (page 388).



COGGIA'S COMET, 1874, JULY 13 (F BRODIE)

This picture is notable for the complicated system of "hoods" on the sunward side of the nucleus, also for the dark central region in the tail, seen in many Comets, which suggests that the head acts as a sort of screen to the region immediately behind it

The Comet's course through the heavens in A D 141 was very similar to that in 1066 In 218 it is mentioned as a fearful flaming star, preceding the death of the Emperor Macrinus

The return of 451 coincided with the defeat of Attila at Châlons The determination of the year is further strengthened by the mention of an eclipse of the Moon on the night of September 26–27 The revolution between 451 and 530 is the longest on record, being nearly seventy-nine and a half years , that between 1835 and 1910 is the shortest, only seventy-four and a half years

In 607 there appear to have been two bright Comets in the opening months It is not quite certain which of them was Halley's, the Chinese descriptions being a little vague In 684 it was described as "like the Moon covered with a cloud" It passed near the Pleiades (page 389)

THE COMET OF 1881 DRAWN ON JUNE 27 (MIDNIGHT) BY MR W F DENNING, AT BRISTOL

This drawing was made with a ten inch reflector and shows an interesting series of more or less parallel bands The parabolic hood round the head is shown This was the first Comet to be successfully photographed

The return of 760 was described in great detail in China In fact, Laugier was able to identify the three apparitions of 451, 760 and 1378 with confidence simply by the Chinese records , they have subsequently been abundantly confirmed by computation of the perturbations There is reason to think that two Comets appeared in 837 , Halley's was seen in China in March Pingré, without knowing what Comet it was, obtained elements quite similar to those of Halley , he gave the inclination as ten to twelve degrees, tending to confirm Hind's conclusion that the inclination has increased A Comet reported in Europe in April does not accord with the Chinese account , it may be a different Comet, or the discordance may arise from the great inaccuracy of early European observations

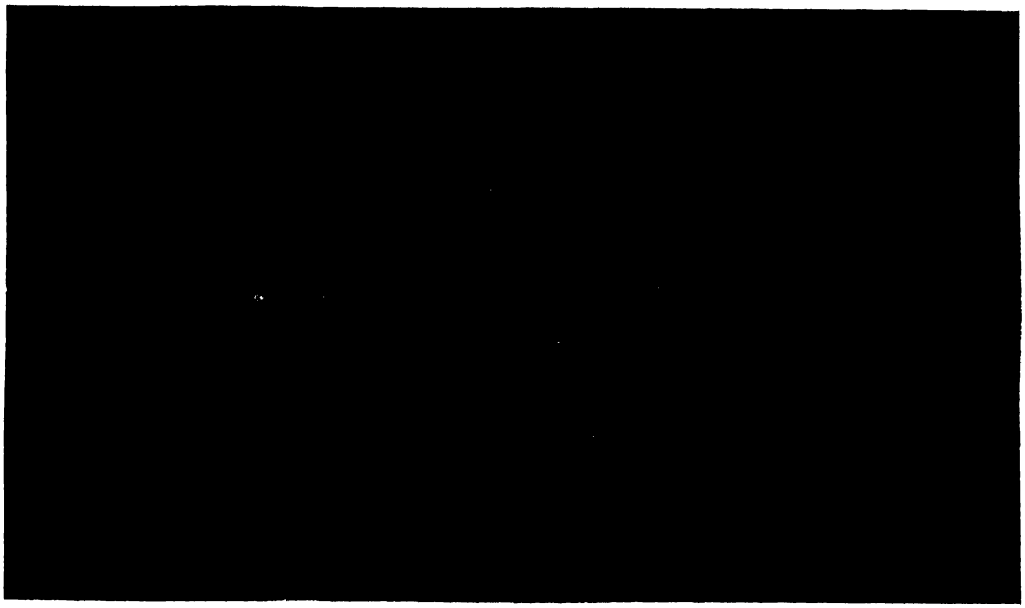
We come now to the famous apparition of 1066, five months before the Norman conquest The Comet was seen by the Chinese in Pegasus on April 2 It was then a morning star, but moved rapidly east, becoming an evening star in the Twins on April 24, its tail then reaching the Plough Finally, it passed on through the Crab into Hydra and Crater (the Cup) It was not unnatural that contemporaries saw in the Comet a portent of the Conqueror's campaign, so that it was given a place in the Bayeux Tapestry (*see* page 390) Hind was the first to identify this with Halley's Comet His predecessors had confidently, but erroneously, taken the Comet of 1006 as Halley's

The apparition of 1222 was one of the few cases where Hind went wrong He supposed the feeble object of July, 1223, to be Halley's , the correct identification was not obtained till the perturbations had been carried back to that point The European records are far from clear, but we can gather from

the Chinese ones that the first appearance was in Bootes the Herdsman, whence the Comet passed through the Virgin, Scales and Scorpion, disappearing near Antares

Pingré, however, misled by some vagueness in the references, stated that the motion was from Scorpio to Bootes, this mistake prevented Hind from detecting that it was Halley's Comet It presented an imposing spectacle The Chinese say that its tail was thirty cubits long, its body being like the planet Jupiter The European records state that it was of the first magnitude, very red, with a long thin pointed tail, stretching towards the zenith "Compared with it the Moon appeared dead, it had no more light, and it joined the Comet"

The return of 1301 again shows the superiority of the Chinese records, those made in Europe gave a misleading idea of the orbit In fact, it was not till 1456 that the European methods showed superiority, but from that point onwards they rapidly improved, while the Orientals remained stationary The returns from 1456 to 1835 are sufficiently described at the beginning of this chapter, or in the legends of the illustrations The 1835 apparition was not remarkable for brilliancy, but many interesting phenomena were seen in the telescope by Smyth and Sir J Herschel (who was then at the Cape), (see

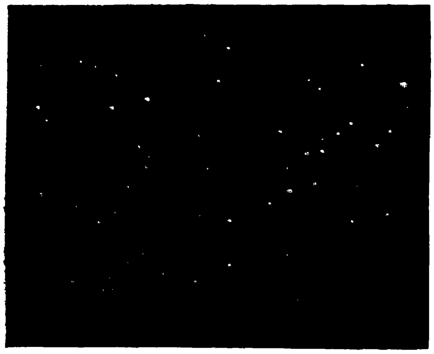


THE GREAT COMET OF 1882 (CHARLOIS)

This picture shows the nucleus and the nearly straight principal tail enveloped by a much fainter hood This appearance was also seen in the Comets of 1901, 1910 January

page 394) The curved hoods round the nucleus were seen, also a luminous sector like that drawn by Hevelius in 1682 The 1910 display was exceedingly fine as seen from southern countries, though many people in England refused to credit the fact, because the view here was impaired by twilight and low altitude The tail reached the prodigious length of 140 degrees, owing to its being so near the Earth, its great curvature was shown by its continuing to be visible in the morning sky for two days after the head had become an evening star The Comet was followed for fourteen and a half months after perihelion, as compared with eight before it, proving that the exciting effects of approach to the Sun continue for some time to increase the brightness Comets are not all alike in this respect, for Encke's Comet is generally easier to see before perihelion than after it, when it becomes large but extremely faint and diffused

A few of the short-period Comets have a sufficiently interesting history to merit a detailed description Encke's Comet was seen in 1786, 1795, 1805 by Méchain, Caroline Herschel, and Thulis respectively, but it was taken for a different object on each occasion, in 1818 the indefatigable Comet-hunter



October 21

October 22

BROOKS'S COMET OF 1893 (IV)

This pair of photographs (by Barnard) shows the shattering of the main tail which occurred between October 21 and 22. The only plausible suggestion to account for this is the possible encounter between the tail and a stream of meteors.

Pons found it at Marseilles. It was on that occasion well observed for seven weeks; Encke undertook the discussion of the observations and quickly found that the orbit differed markedly from a parabola, being an ellipse of quite moderate size. He saw the probability of identity with the three Comets just mentioned, and by a wonderful feat of computing he carried back the planetary perturbations for thirty-two years in the short space of six weeks, thus rendering it certain. This achievement led to the Comet being called Encke's, though he was not the discoverer. This was the second Comet to be recognised as having appeared more than once, and it has much the shortest period, three and one-third years, of any known Comet. After three periods, or ten years, the conditions of visibility are nearly repeated. Returns in the winter months are the most favourable for observation in Europe, and it will be noticed that those of 1786, 1795, 1805 were all winter returns. When the Comet returns in our summer months, it is only observable in the southern hemisphere. It has not been missed at a single return since 1818, and its orbit is therefore very accurately known. There are several points of interest about it. It passes inside the orbit of Mercury when nearest to the Sun, and occasionally (as in 1835) passes near enough to that planet to be considerably perturbed. It is from these perturbations that the most reliable value of the mass of Mercury has been deduced; Backlund found the value one-twenty-seventh that of the Earth, or three times that of the Moon. It is well to note that the result of the perturbations only becomes manifest in the following return; in this case in 1838. They cause a slight alteration in the speed and direction of motion, but it takes time for an appreciable disturbance of the Comet's position to develop. Suppose some small mishap to a motor bicycle caused the speed to diminish by one-tenth of a mile per hour. One minute after the accident the bicycle would be only three yards behind the undisturbed position; but five hours later, it would be half a mile behind, which would be quite appreciable. It was a near approach to Jupiter in 1835 that hastened the return of Halley's Comet in 1910 by over a year.

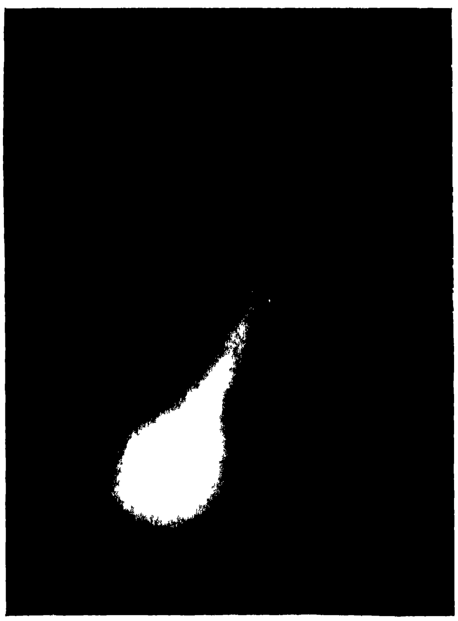
Encke's Comet shows an unexplained shortening of the period (apart from the calculated effect of planetary action). Encke gave the period in 1789 as 1,212.79 days, and in 1858 as 1,210.44 days. As twenty-one periods intervene, the average shortening per period was one-ninth of a day, or two hours forty minutes. It has been conjectured that this may be the result of retardation by a resisting medium; it has been objected to this explanation that other short-period Comets fail to show the effect. But the difficulty can be surmounted by assuming that the medium does not extend appreciably beyond the orbit of Mercury; Encke's is the only one of the short-period Comets that passes sufficiently near to the Sun to be affected by it.

A more puzzling feature has been established by the work of Prof Backlund, who continued the minute study of this Comet that Encke had begun, this is that the amount of acceleration in the motion has altered at certain dates In 1858 it diminished by a fifth of itself, and again diminished by a like amount in 1868 In 1895 it again diminished by twenty-eight per cent, and suffered a further loss in 1904 or 1905, when the acceleration fell to one-ninth of its value before 1858 In each case the change of velocity appears to have taken place in the neighbourhood of perihelion, and Backlund noted that all the changes occurred at times of considerable solar activity, though the evidence is too scanty to assert that this is other than a chance coincidence It would seem that the density of the resisting medium has diminished at the region where the Comet crosses it, this might arise from the orbit intersecting that of a meteor swarm, whose density or the position of its orbit was slowly changing Backlund made a suggestion to explain the sudden diminution in brightness of the Comet after perihelion It is that the Comet particles are flat, and kept in a particular plane by electrical forces When the Earth is in their plane the particles are seen edgewise, and reflect very little light

The return in 1924 is a favourable one for northern observers, and the Comet will be visible in a small telescope, it may possibly be glimpsed by the naked eye, if one knows where to look The nearest approach to the Sun will be on October 31 I may mention that I deduced this date by making use of the cycle of fifty-nine and a half years, being eighteen revolutions of the Comet, and about five revolutions of Jupiter and two of Saturn It follows that the Jupiter and Saturn perturbations repeat themselves almost exactly, and one is saved the trouble of recomputing them, unless one is aiming at extreme accuracy

Biela's Comet has already been mentioned, but deserves a fuller description It was seen by Montaigne as far back as 1772, and again by Pons in 1805, but at neither apparition was its short period detected It was again seen by Biela on February 27, 1826, and by Gambart on March 9 The French frequently call it Gambart's Comet, but while the use of the combined title Biela-Gambart would be in accordance with practice the omission of the former name is not justifiable

It was observed for eight weeks at this apparition, which enabled its period (six and a half years) to be determined, and its identity with the Comets of 1772 and 1805 established It was seen again in 1832, missed in 1839 (being badly placed for observation) and found in 1846 to have divided into two Comets There had been earlier reports of Comets dividing into two or more portions, but they were less strongly confirmed than this one, and the possibility of such an occurrence had been scouted by



July 8, 1893

July 13, 1893

THE RORDAME QUÉNISSET COMET, 1893 (II) (W J HUSSEY)
The notable feature of the tail of this Comet is that it is distinctly narrower than the coma Its motion among the stars was rapid, hence they appear as lines Various knots can be seen in the tail Their outward motion gives a measure of the repulsive force

the great Cometographer Pingré There were perplexing changes of brightness in the two components Both the components were seen again in 1852 somewhat farther apart, but since that date they have never been seen, though meteor showers belonging to the Comet's system have been observed on several occasions, notably in 1872 The orbit intersects that of the Earth, and this fact caused much absurd panic in 1832 As a matter of fact the Earth was a month's journey distant when the Comet crossed its orbit, but even if collision had occurred there was no reason to apprehend serious consequences

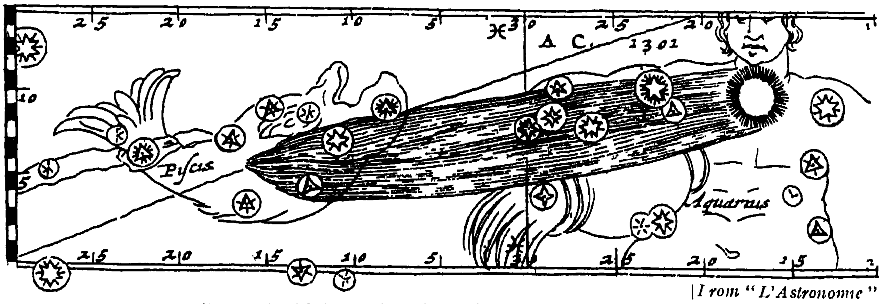
The Comet Pons-Winnecke (often but wrongly called simply by Winnecke's name) was discovered by Pons in 1819, and at that time found by Encke to have a period of five and a half years It was not, however, seen again till it was recovered by Winnecke in 1858, since which year it has been seen at most of its returns, the last being in 1921, when there was again some popular apprehension owing to a fairly close approach to the Earth An interesting feature of the orbit of this Comet is the large increase that has taken place in the distance of the Comet from the Sun at the point of nearest approach

After Longbottom] DELAVAN'S COMET, SEPTEMBER, 1914 [*From "Knowledge"*

This Comet was discovered nearly a year before its nearest approach It became an interesting object in the telescope, and it was only its great distance from the Sun that prevented it from being splendid It marked the opening of the War

In 1819 the distance was 72 million miles, not much more than that of Venus, in 1875 it was 77 million, in 1886 82 million, in 1898 86 million, in 1921 96 million, or two million miles outside the Earth's orbit

Pons also saw a Comet on two days in February, 1808, which is likely to be the same one It is also not quite impossible that it may be identical with one found by Helfenzrieder in 1766, and calculated to have a period of about five years Its least distance from the Sun was only 38 million miles, very little greater than that of Mercury These changes are known to be mainly due to the action of Jupiter, to which the Comet has made several fairly close approaches Any person with leisure to carry back the computation of perturbations from 1819 to 1766 could settle the question The meteors belonging to the Comet were seen for the first time in 1916, when they provided quite a notable display, a smaller one following in 1921, previously the orbit had been too distant from that of the Earth to permit of their being seen The period of the Comet has lengthened from five and a half to six years, and another approach to the Earth will occur at the end of June, 1927, when Mr C Merfield calculates that it will be only two million miles away As the meteors are scattered on each side of the Comet's



[From "L'Astronomie"

THE SECOND COMET OF THE YEAR 1301

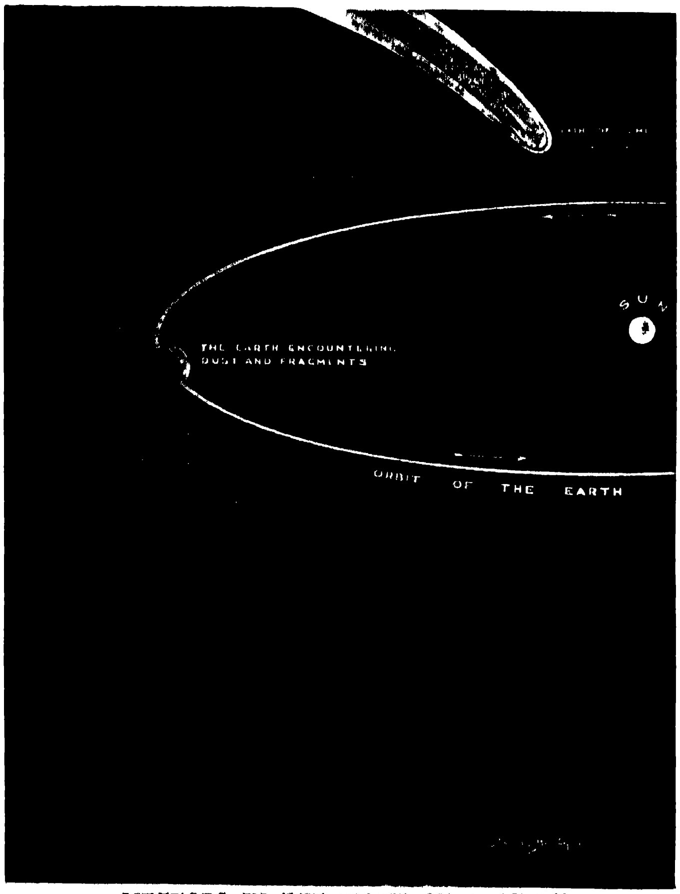
This Comet, which appeared about Christmas, 1301, in the Waterman and the Fishes, was apparently not that of Halley, which appeared in September, 1301, and followed a course very similar to that in 1607 (See the lower figure, page 392)

track, they may again be seen then, but as they share in the outward shift of the orbit it would seem that this shower is not likely to be visible for more than a few years in the future

Wolf's Comet affords a good illustration of the fact that the action of Jupiter may work in either direction The Comet was first seen in 1884, when it was found by calculating back that it had been near Jupiter in 1875, before that date its orbit passed so far outside that of the Earth that the Comet was too faint to observe The Comet was again near Jupiter in the autumn of 1922, and, curiously enough, Jupiter seems to have exactly reversed its behaviour in 1875, sending the Comet back into its former orbit There is just a chance that powerful telescopes may be able to pick it up in 1925, its position being known Otherwise it will have to be added to the list of lost Comets

Holmes's Comet of 1892 behaved in an unusual manner When found it was very bright, in the same field with the Great Andromeda nebula It must have brightened fairly rapidly, as photographs of the region, taken not long before, failed to show it It then commenced to expand, becoming fainter as it did so, and at the end of two months it was so large and faint that it was practically impossible to observe it Then, to the surprise of astronomers, a new bright region appeared in the middle of it, which in turn expanded and grew fainter We may conjecture that something in the nature of an explosion, driving the cometary matter violently outwards, occurred on each occasion The Comet was seen again in 1899 and 1906, but never repeated its brilliant display of 1892 In 1919 it could not be found, though its position was favourable, so it probably affords another case of disintegration

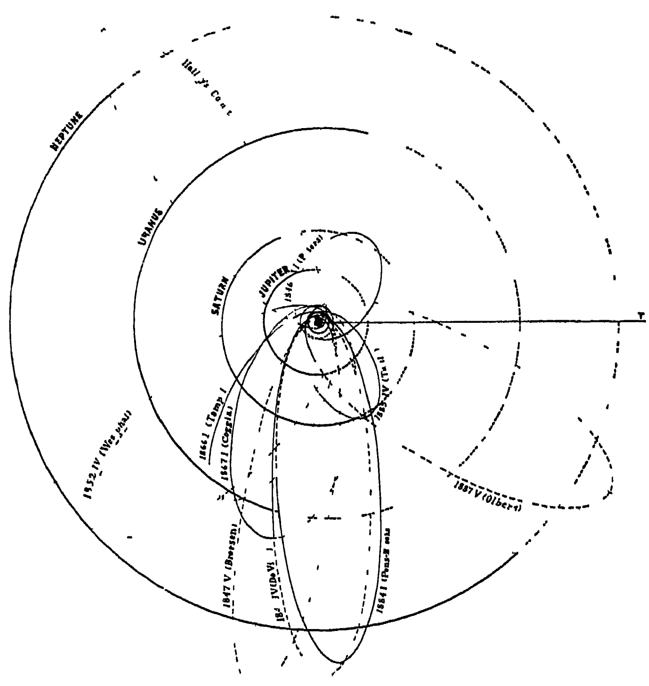
Brorsen's is the second lost Comet of short period It was found by Brorsen at Kiel on February 26, 1846, its orbit was proved to be an ellipse with period about five and a half years, it



METEORS IN THE WAKE OF A COMET.

Besides the tail of a Comet, which does not lie along its orbit, the Comet is followed by an assemblage of meteoric débris It must, however, be understood that this is not visible, as the picture suggests The meteors cannot be seen unless they enter the Earth's atmosphere

was well placed for observation at alternate returns, being missed in 1851, seen in 1857 (fairly bright and large), missed in 1862, observed in 1868, 1873 and 1879, in the last return it was bright enough for observations of its spectrum to be made, this was of the usual hydrocarbon type It has never been seen since 1879, though it was carefully sought for in 1890, when its position as calculated was quite favourable There was no very close approach to Jupiter about this time to account for the disappearance It must have been near Jupiter in 1842, before it was discovered, but another close approach is not due till 1937 Its disappearance illustrates the general fact that we cannot predict that any of the short-period Comets will actually be observed in a particular year, in several cases, even when the perturbations have been calculated, and the conditions seem favourable, search has been made in vain



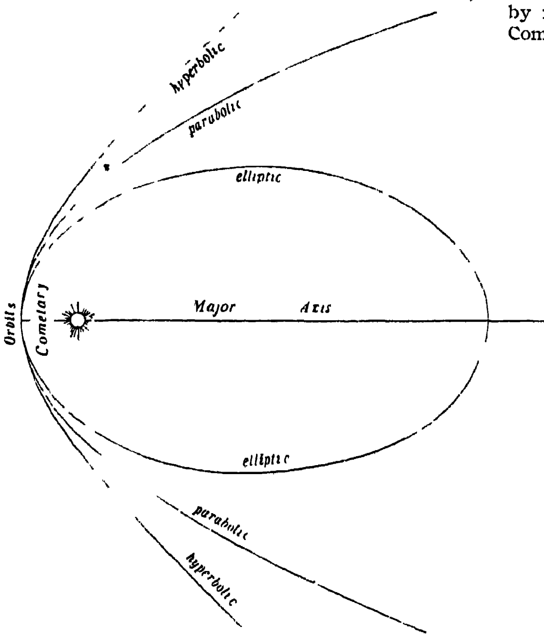
Drawn by] [*H C Wilson*

THE COMET FAMILIES OF SATURN, URANUS, AND NEPTUNE

The picture shows how the aphelia of the Comet orbits are grouped near the orbits of the parent planets Saturn has two Comets (Tuttle and Peters), Uranus two (Tempel and Coggia), but Neptune has seven, that of the 1827 Comet not being shown Halley's is a splendid Comet, by far the grandest of all the periodic ones, while the Pons Brooks Comet is also interesting Five of the Neptune Comets have been seen at two apparitions, at least

The latest addition to the Jupiter family is the Comet Grigg-Skjellerup Mr John Grigg, of Thames, New Zealand, found a faint Comet in Virgo on July 22, 1902 He sent a telegram to Melbourne Observatory, but this was delayed for some reason, so we have no observations except the discoverer's, which are unfortunately very rough, and extend over only twelve days They were quite inadequate to show the ellipticity, and a parabolic orbit was assumed

However in May, 1922, Mr Skjellerup found a Comet at the Cape of Good Hope, when it had been observed for some days Messrs Crawford and Leuschner, of Berkeley, California, deduced that it had a short period, and conjectured that it was identical with Grigg's Comet of 1902, subsequent calculations by Mr G Merton, utilising some photographic observations made at Greenwich two and a half months after the discovery, made the identity almost certain The Comet had completed four revolutions in the interval, its period being five years less eleven days The Comet should be seen again in 1927, at about the same time as the Comet Pons-Winnecke, its period is the shortest of any known Comet, with the



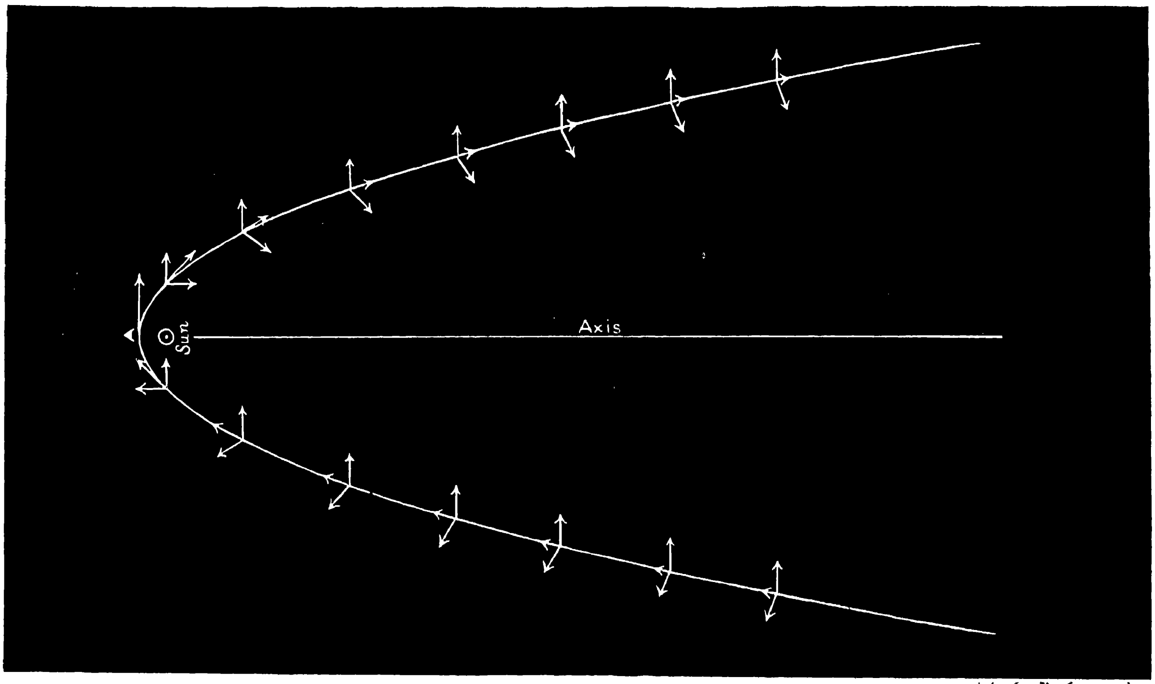
FORM OF COMETARY ORBITS

Several cases of all of the above forms of orbit are known, though the hyperbolic ones are almost indistinguishable from the parabolic Near the Sun the shapes of all three forms are similar, so observation over a fairly long arc is necessary to decide the character of an orbit

exception of Encke's. Another Comet of interest is that of Giacobini, discovered in December, 1900, and found to have a period of six and a half years. It was seen again in 1913, and may be expected again in the autumn of 1926, when it will be near the Earth; this is one of the Comets that may be expected to give a meteor shower, owing to its orbit passing near the Earth's position in October.

A Comet found by Neujmin on September 6, 1913, has a period of eighteen years. Its appearance was unusual; it frequently showed no nebulosity, and looked exactly like an asteroid; however, on September 24 a short fan-shaped tail was photographed at Heidelberg.

Some explanation may be given of the method by which a Comet's orbit is deduced from the observations. Three observations are required to obtain an orbit; each observation consists of two elements, which are called Right Ascension and Declination, corresponding exactly with longitude and latitude on a terrestrial map. We thus have six observed quantities, which conjoined with the times of observation enable us to deduce the six elements of the orbit; these are (1) the time of passing perihelion,



[A. C. D. Crommelin

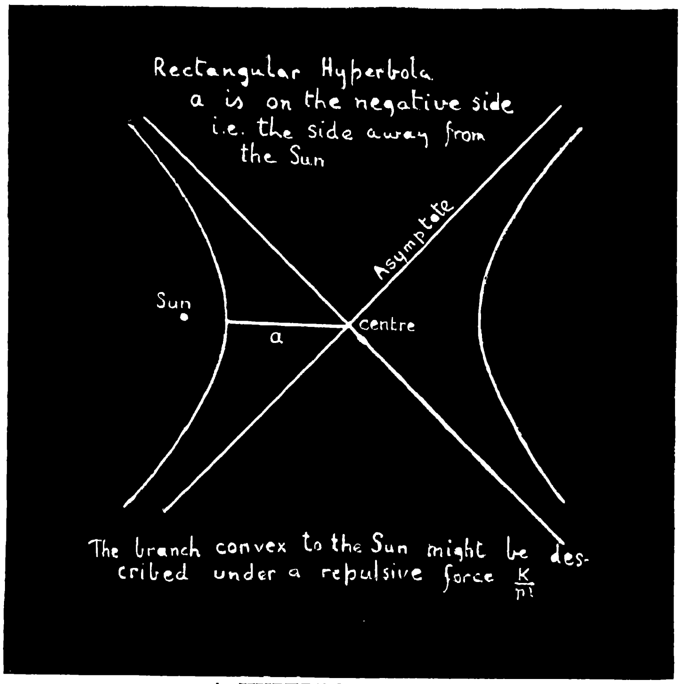
VELOCITY OF COMETS IN PARABOLIC ORBITS

The parabolic curve is familiar as being the course of a rocket or a jet of water from a hose. Most Comets have appreciably parabolic orbits. The velocity in such an orbit is the resultant of two equal constant velocities, one perpendicular to the axis, the other perpendicular to the line joining Sun and Comet. At the vertex A the two components are in the same direction, so the resultant velocity is greatest here, and gets steadily smaller as we pass away from this point

(2) the direction of the perihelion point looking from the Sun, (3) the direction of the ascending node or point where the Comet crosses the plane of the Earth's orbit from south to north, (4) the inclination or slope of the orbit to that of the Earth, (5) the distance from the Sun at perihelion, (6) the period of revolution, or the eccentricity; we can deduce one from the other when we know (5).

In the case of an elliptical orbit we need all the six observed quantities; these in some cases yield one solution, and in others two solutions; but if we commence by assuming the orbit parabolic (which is generally done in the case of new Comets), we treat (6) as known, the eccentricity being unity and the period infinite; we then need only five observed quantities, and the accuracy with which the sixth quantity fits in with the deduced orbit is a test as to whether the orbit is really parabolic; but it is not safe to assume an elliptical orbit from a short observed arc, as the discordance may simply arise from want of precision in the observations. A Comet is frequently ill-defined, and difficult to observe

accurately Without entering into mathematical details we may note that the distance of the Comet from the Sun is deduced from the curvature of the observed arc, that is the amount by which the three observed positions, when plotted on a diagram, deviate from a straight line Part of the curvature is due to the fact that the Earth from which our observations are made, is itself following a curved path round the Sun A trial-and-error method is generally necessary to separate the curvature due to this source from that due to the Comet itself



A HYPERBOLIC ORBIT

The study of Orbits is incomplete without including the hyperbola A few Comets move in hyperbolae, which are, however, much closer to parabolae than the one in the picture The tail matter of Comets describes the convex branch, under a repulsive force from the Sun The distant part of the curve practically coincides with the asymptotes

Lambert deduced an elegant theorem if the observed arc is concave towards the Sun, then the Comet is nearer the Sun than the Earth is, if the arc is straight, the distances of Comet and Earth from the Sun are equal, if it is convex towards the Sun, the Comet is the more distant This test fails if all three positions lie on (or very close to) the ecliptic, in that case the plane of the orbit agrees with that of the Earth's orbit and the arc appears straight at all distances We then need a fourth observation to find the orbit elements, which are deduced from the change of rate of motion of the Comet, instead of the curvature, which is now zero

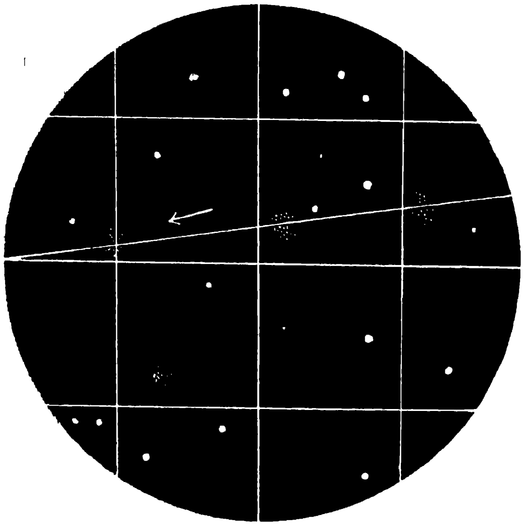


DIAGRAM ILLUSTRATING THE METHOD OF DISTINGUISHING A MOVING NEBULOUS OBJECT IN A FIELD OF FIXED STARS

Sometimes objects, suspected of being Comets, are really nebulæ, stationary among the stars A Comet, if watched, will be seen to move through the stars, as shown by the arrow This test should be applied wherever possible

There are now very few astronomers engaged in the search for new Comets, and this may be recommended as a hopeful field of work for the amateur who possesses a small telescope He should use his lowest power, and sweep by preference over the low western sky just after dark, and the low eastern sky just before the dawn A Comet may, however, be found in any region of the heavens In cases where a tail is present, the cometary nature of the body may be at once manifest, but in most cases a new Comet appears as an ill-defined misty patch, and there is danger of confusion with nebulæ In these cases no definite announcement should be made until the object has been seen to move among the neighbouring stars A careful diagram of the field should be made, and repeated an hour later The observer must not be deceived by the apparent rotation of the field produced by the diurnal motion A star that is high left of another east of the meridian will appear high right after passing the meridian This change corresponds to a page of a book being slowly turned

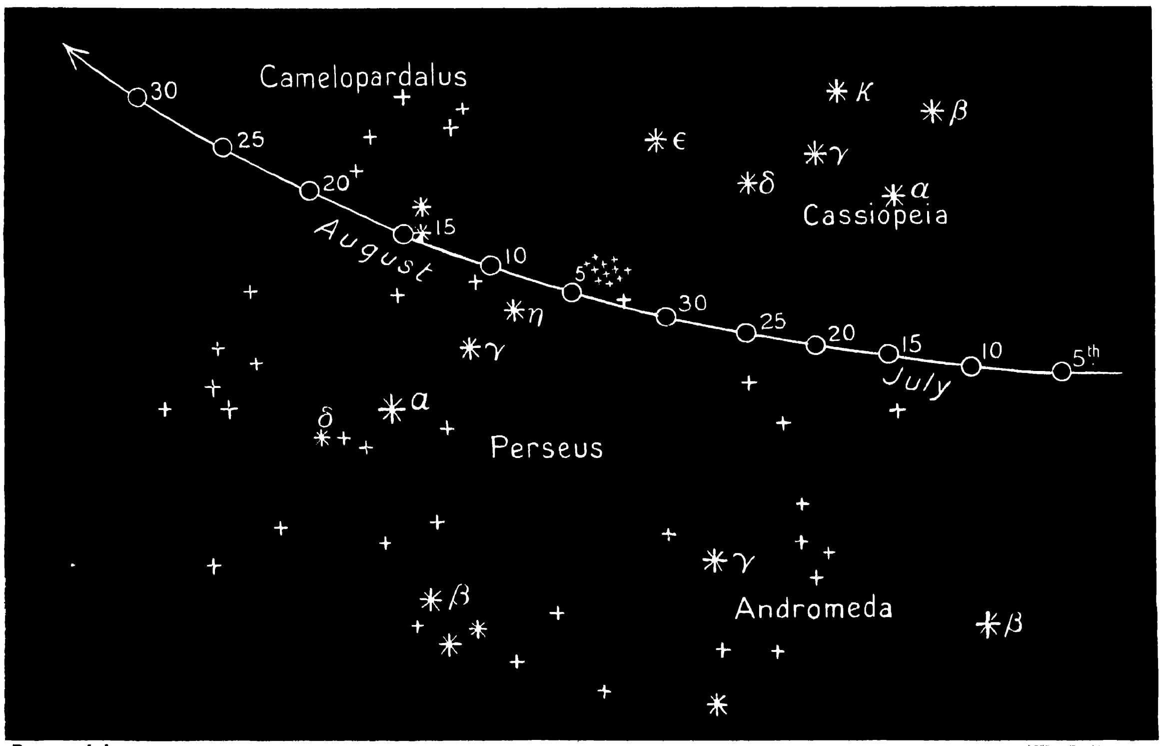
round, whereas the change required to prove the cometary character of the body corresponds to one letter on the page slipping out of its place in a word

If the discovery is confirmed by observed motion, prompt and full information should be sent to official astronomers, the discoverer, if first in the field, will have the satisfaction of having his name permanently attached to the body There are now no exceptions to this rule, though in the past there are some cases where the names of men who have made extended researches on a Comet are substituted for the actual discoverers Halley's and Encke's Comets are examples

FALLING STARS

By W F Denning, F R A S

That branch of Astronomy relating to objects variously known as Fireballs, Bolides, Meteors, and Falling Stars is a modern one so far as its systematic study is concerned For ages and ages the sky had given striking evidence of these brilliant but transient phenomena, and they were sometimes commented on but regarded with superstitious awe, and mistaken in their meaning and character They were supposed to be atmospheric in origin and due to the ignition of columns of gases generated



Drawing by] [*W F Denning*

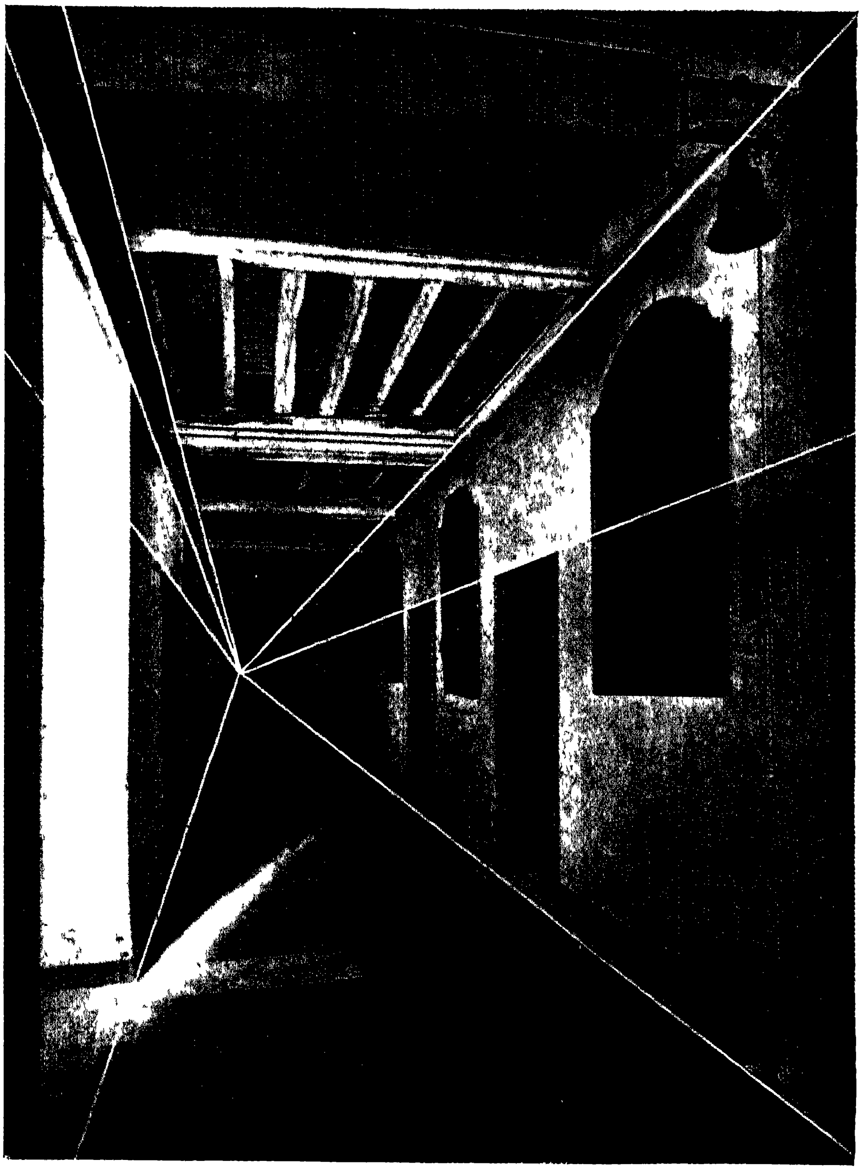
MOVEMENT OF THE PERSEID RADIANT DURING JULY AND AUGUST

The members of a stream of meteors move in parallel paths, but the Earth, during the weeks of its passage through a broad stream, is constantly altering the direction of its motion as it revolves round the Sun The effect of this is to make the meteors appear to come from a slightly different point each night

in the air Men had, however, made these assumptions based on imperfect knowledge, and had commenced to theorise before they had sufficiently observed

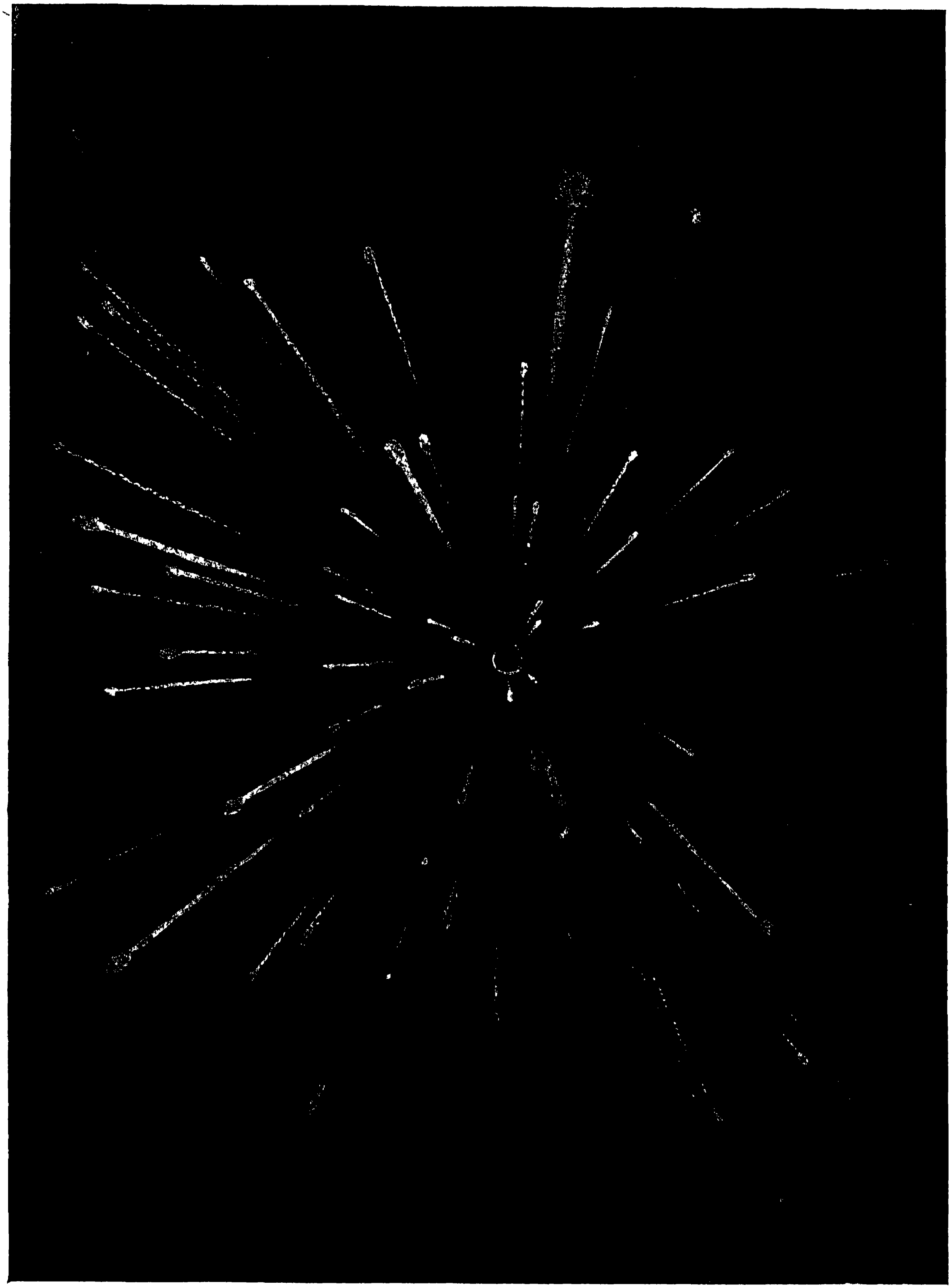
Thus Meteoric Astronomy remained in a practically neglected and uncultivated condition until about one-third of the Nineteenth Century had passed Then, in 1833, fortunately one of those brilliant and rare celestial spectacles—a great meteoric storm—occurred which made people stop

and wonder Thereafter, it engaged the thoughtful attention of mankind and brought the dawn of a new and more reliable Meteoric Astronomy Heis, Coulvier-Gravier, and their contemporaries began to make habitual observations of a more exact and extensive nature than had been hitherto attempted, and gradually the truth began to be realised that Falling Stars belonged to the domain of celestial phenomena and came from outside space to be consumed in our atmosphere as a result of its resistance to their violent impact They were seen to be small planetary bodies moving in orbits around the Sun, and Schiaparelli's discussions soon proved that they were allied to comets and really manifestations of these bodies in another form Falling Stars were henceforth regarded as an important and attractive branch of Astronomy One of the most striking and vivid aspects of Nature is presented when a large Meteor bursts upon the view Night is transformed into day for a moment as a globe of light, electric in its dazzling intensity, glides athwart the firmament A stream of sparks follows it, but the whole apparition quickly dies away, leaving the shades of night blacker than before from the effects of contrast



TERRESTRIAL PERSPECTIVE
In the interior illustrated above the lines which recede from the observer appear to converge towards one spot, known to artists as the "vanishing point" Actually, of course, these lines are all parallel and maintain constant distances from one another, their apparent convergence is only an effect of the position of the observer

People have wondered in all ages what these great celestial bombshells are and how they come to make such lustrous displays on the deep azure of our nocturnal skies Science answers that they are the stone, or stone and iron, fragments of wasting cometary systems revolving around the Sun and encountering the Earth in her orbit Dashing into her atmosphere at a velocity differing, according to the conditions, from forty-four to eight miles per second, they become heated as



Drawing by] [*W. F Denning*

CELESTIAL PERSPECTIVE

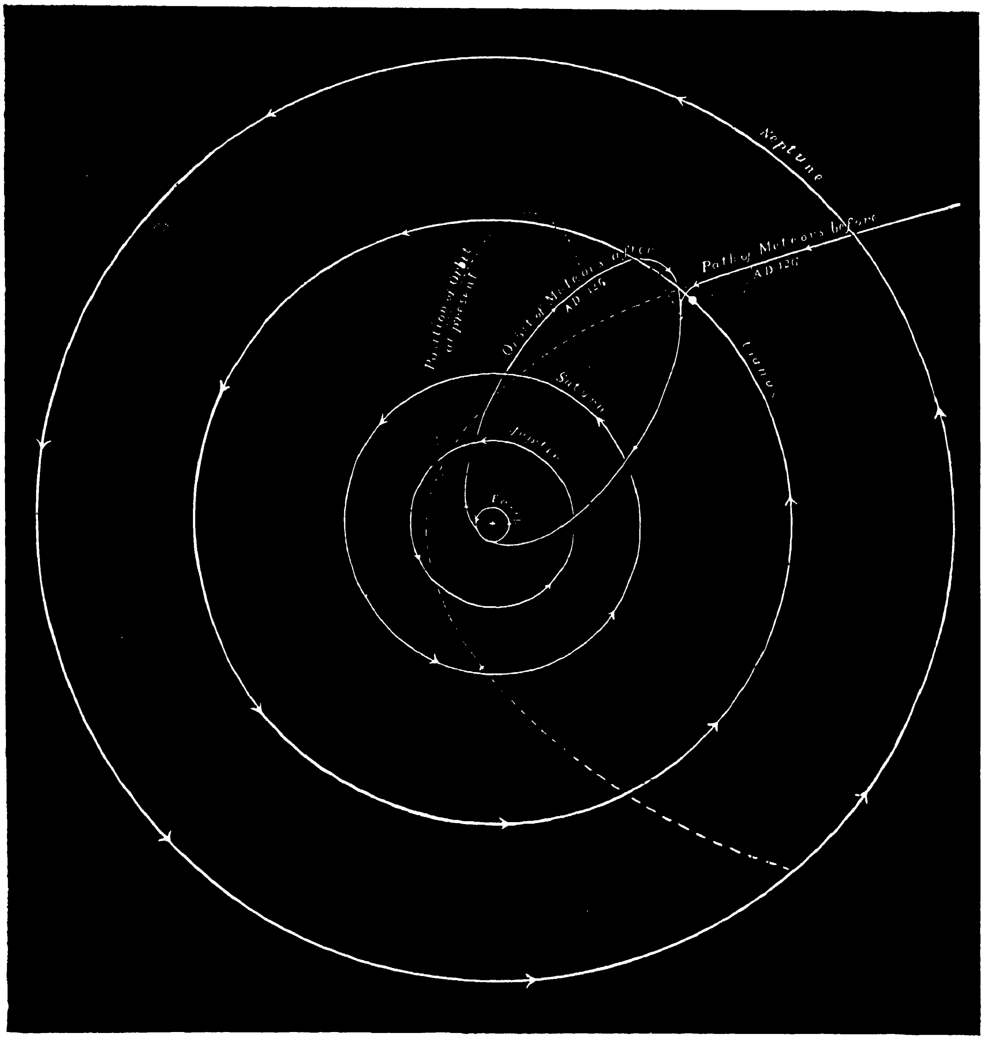
The members of a shower of meteors appear to move radially outward from a common centre, like the spokes of a wheel In reality all are moving in parallel paths and their apparent divergence is an effect of perspective Much the same effect would be obtained by placing a camera among a number of telegraph wires and taking a photograph of the nearest post As a rule, the meteors composing a shower appear at intervals, one by one, but occasionally (as in 1833 and 1866) a large number appear together, and the effect illustrated above is then strikingly brought out.

a result of air resistance Incandescence occurs and so the rushing fireball develops its transient glories, and sometimes its terrifying explosions are heard in the stillness of night Our atmosphere is our protection Myriads of Meteors pour into it every hour, yet only one of millions can penetrate right through the vaporous envelope and hurl itself to the ground In the fiery ordeal to which they are subject nearly all of them perish far above the Earth's surface and are reduced to the dust out of which they had their being

A Fireball seen on November 23, 1877, caused a deafening sound which was computed by Colonel Tupman to be at least one hundred times greater than a peal of thunder

We may hold a Meteorite in our hand and look upon a wonderful object which, for millions of years in the past, had perhaps been circulating not only among planets and comets, but far outside the boundaries of our Solar System

Possibly the great clouds and streams in which they revolve were originally ejected from planets or remote stars In any case space is teeming with them and we know not their exact source or ultimate destiny In the bright flash which attracts the eye in the darkness of a midnight hour, we only perceive the ignition and collapse of a little planetary world!

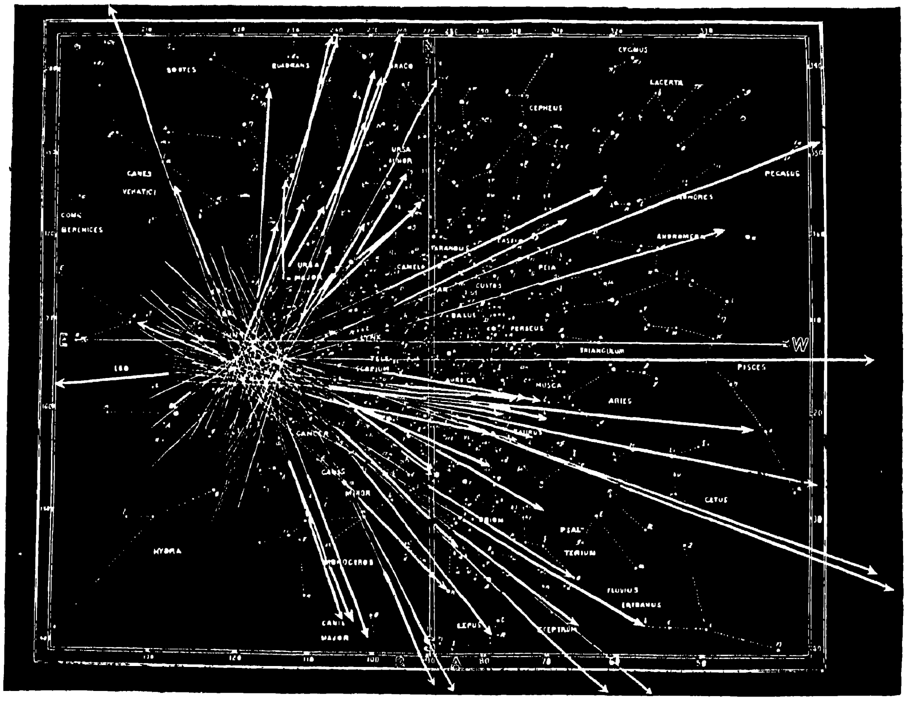


THE CAPTURE OF THE LEONIDS

Calculation shows that in the year A D 126 the swarm of meteors which we now know as the Leonids made a very close approach to the large planet Uranus, whose gravitational attraction entirely altered the size and shape of their orbit round the Sun The direction of motion was also changed, and the meteors now revolve in a direction opposite to that of the planets Since the year 126 the shape and size of the orbit have not changed much, but it has shifted round bodily in an anti-clockwise direction

Early historical records of Meteors do not materially help modern investigations, as they were usually imperfect and inaccurate Ancient

references to certain remarkable star-showers have been of some little service, however, and Herrick and Quetelet were successful in forming lists of these and thus guiding and assisting enquiries as to past periodical returns of the Lyrids of April, the Perseids of August, and the Leonids of November Chronicles of former meteoric displays though quaint, vague and imperfect in certain respects, furnished the dates and proved that Perseids in past times came in July and Leonids in October



THE LEONID RADIANT
The meteors recorded on the star map above were observed at Greenwich during the great shower of Leonids which occurred on 1866, November 13 So many meteors were seen on that night that there was only time to record the brighter ones It will be seen that all appeared to diverge from the same area in the Sickle of Leo

Biot discovered in the *Matuanlin* (an ancient Chinese record of events) sixteen falls of Aerolites for the interval between the middle of the Seventh Century B C and the year 333 of our era, whereas Greek and Roman writers only mention four of these phenomena

Humboldt, in his "Cosmos," made some interesting references to meteoric history, and gave some useful advice which might well be considered at the present day "The progress of our knowledge concerning igneous meteors will be the more rapid the more impartially facts are separated from opinions, so that, while carefully sifting or testing all alleged particular facts, on the one hand, we may not, on the other, fall into the error of rejecting as bad, or as uncertain observations, whatever results we are not yet able to explain It appears to me most important to separate physical relations from those geometrical and numerical relations which admit, generally speaking, of more certain and assured investigation "

The Chinese, Chaldeans, and others among the ancients, must have frequently noticed striking examples of falling stars and fireballs, though they misunderstood their meaning and failed to realise their importance The Chinese, fortunately, made it a practice to record notable events in registers, and we have to thank them for the oldest descriptions of meteoric falls These date back to 644 years before the Christian era

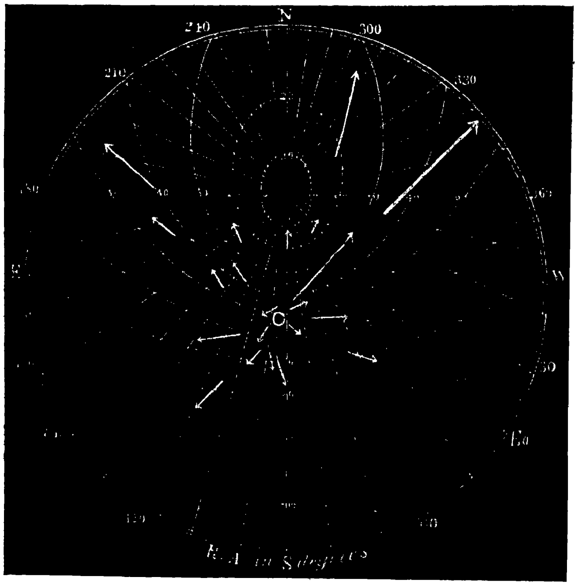
The views of old natural philosophers regarding these phenomena were not always crude and erroneous, for Plutarch, in the "Life of Lysander," says "It is a probable opinion which was held by those who said that shooting stars are not emanations or overflowings from the ethereal fire which become extinguished in the air immediately after being kindled, and that neither are they produced by ignition and combustion of a quantity of air which has detached itself from the upper regions, but rather they are heavenly bodies which fall or are cast down in consequence of an intermission or irregularity of the force of rotation and are precipitated not only on inhabited countries,

but also in greater numbers, beyond these into the great sea so that they remain concealed" (Humboldt, *Physical Description of the Heavens*, 1866)

It is certain that though observational facts were few and could afford little help to reliable conclusions, yet some of the ancient philosophers had a sound and far-seeing judgment in interpreting correctly some of the most marvellous operations of Nature

The great Meteoric Stone which fell at Ægos Potamoi, in 468 B C , was a grand phenomenon which much affected the Hellenic races and directed their philosophers to a closer study of natural events of this character The Meteor fell on the same ground as that on which, in 406 B C , a battle was fought and won by Lysander over the Athenians, and this defeat marked the end of the Peloponnesian War

Schmidt, Baden-Powell, Herrick, A S Herschel, and many others maintained the work of the earlier pioneers and continued to accumulate observations and discuss phenomena But researches were rendered difficult by the transitory nature of the objects and the necessarily hurried and imperfect observations obtained of them



PATHS OF METEORS FROM ONE "RADIANT"
As each meteor is observed its path is drawn on a chart of special type, like that shown above The tracks thus marked are then produced in a backward direction and are, in the case of a definite "shower," found to intersect in one small area, known as the "radiant point"

There are comparatively few astronomers, either professional or amateur, who cultivate the meteoric branch They evidently do not regard it as an attractive study In any case, it does not appeal to them sufficiently to enlist their practical sympathies, and so it has been comparatively neglected in recent years A few ardent observers have, it is true, continued to devote themselves to the subject, and two English ladies, Miss A Grace Cook and the late Mrs Fiammetta Wilson, endeavoured to arouse more enthusiasm in this field of work both by practical example and advice, and it is hoped that this department may ultimately profit to the extent it so well deserves

There is no question that the study of Meteors and their various phenomena offers the prospect of important discoveries and striking developments in the extent of our knowledge in the immediate future Much has already been accomplished, but much more remains to be done It may be correctly described as a young section of astronomical enquiry, for its suitable investigation has been proceeding for less than a century The pioneers in this branch adopted the best method of recording Meteors and initiated the derivation of their radiant points, for it was soon recognised that the luminous flights of these objects were not all discursive and at random in the firmament, but that they had certain definite centres of divergence Thus, the Meteors which had long been known to fall abundantly in the first half of August were seen to emanate from Perseus, in other words, their paths if carried back in the same line of direction, intersected in Perseus Similarly, the very plentiful displays of Meteors which had been witnessed in the second week of November were observed to have a community of origin, the focus of their radiation being in the Sickle of Leo

Heis and Schmidt determined a number of these radiant points and found they were very numerously scattered over the celestial vault, though mostly produced by showers of feeble character The systems of August and November were evidently of very special richness and character among the host which indicated their presence at all seasons and in every part of the heavens

As Heis and others of his time brought the awakening dawn into this branch of Astronomy, so

may Schiaparelli and his contemporaries a generation later be said to have introduced that greater illumination of the subject, which has preceded the fuller light to be finally expected from present and future investigations.

The following is a list of a few of the chief Meteoric displays of the year:—

Name of Shower	Date of Maximum	Radiant Point α δ	Appearance of Meteors
Quadrantids	January 3	230° + 52°	Slowish, long paths
Lyrids	April 21	270° + 33°	Swift, streaks
η Aquarids	May 2–6	338° − 2°	Swift, very long paths
Draconids	June 28	228° + 54°	Very slow, short paths
δ Aquarids	July 28–30	339° − 12°	Slow, long paths
α Capricornids	July 25–August 4	303° − 10°	Very slow, brilliant, long
Perseids	August 11	45° + 57°	Swift, streaks
Orionids	October 19	92° + 15°	Swift, streaks
Leonids	November 11–15	151° + 23°	Very swift, streaks
Andromedids	November 17–27	25° + 44°	Very slow, short, trained
Geminids	December 11–12	110° + 33°	Swift, white, short paths

The figures in column 3 under the Greek letters α and δ denote the Right Ascension and Declination (which are analogous on a map of the sky to latitude and longitude on a map of the Earth) of the point in the sky from which the Meteors appear to radiate.

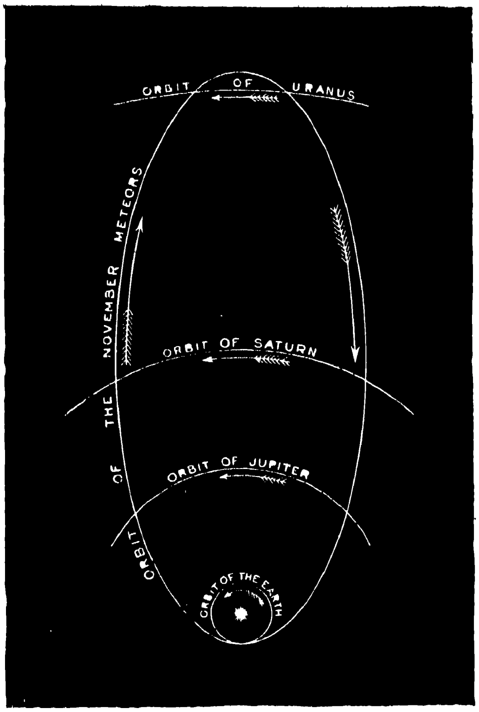
Nearly all the Meteors that enter the Earth's atmosphere are dissipated by volatilisation at the high temperature attained. But very occasionally one survives, as already stated, and gets right through the obstructing air strata to alight upon the ground. It does not reach it with the same planetary speed it originally had, but with greatly reduced velocity due to atmospheric resistance, etc. Its final descent is made at a speed scarcely exceeding that of a terrestrial body falling from a height. In fact, when spent Meteors usually reach the Earth their directions are nearly or quite perpendicular, and the motion is reduced to 400 or 500 feet per second.

In the cases of several falls, the objects penetrated the soil to only twelve or eighteen inches, and it was possible to calculate their speed prior to alighting.

The Meteorites which have fallen in the United Kingdom during the last 130 years, and are thoroughly well-attested, include the following:—

1795 (December 12)	Wold Cottage	56 lbs
1830 (February 13)	Taunton	2¼ lbs
1835 (August 4)	Aldsworth	1 lb 2 ozs
1876 (April 26)	Rowton	7¾ lbs
1880 (March 14)	Middlesbrough	3½ lbs
1902 (September 13)	Crumlin, Ireland	9¼ lbs
1914 (October 13)	Appley Bridge, Wigan	33 lbs
1917 (December 3)	Perth, Scotland	38 lbs (4 pieces)

From these figures the average rate of fall would appear to be about one in every sixteen years, but the period is not long enough to yield a reliable deduction.



THE ORBIT OF THE LEONIDS

This diagram shows the relations of the Leonid orbit to those of the Earth and other planets. It was shown by Schiaparelli and others that the Comet discovered by Tempel in 1865 moved round the Sun in the same path as the Leonids.

It is obvious that a great many Meteorites must descend upon our globe (either on land or sea) without being observed at all By far the greater area of the Earth is covered with water, and much of the land portion is sparsely inhabited, so that falling bodies would generally elude notice People show a disposition to congregate in towns and leave vast tracks mere " country-side "

These bodies are described according to their chief composition, viz Stone = Aerolites, Iron = Siderites, Iron and Stone = Siderolites The all-iron Meteorites are rare and not many instances are known The Rowton Meteorite, of April, 1876, was of iron, and reckoned as only the seventh example ever seen to fall

PHOTOGRAPH OF A LEONID

This meteor, photographed on 1901, November 14, was a member of the famous Leonid swarm It was travelling almost directly towards the camera, hence the apparent shortness of its path The interruption of the latter shows that the meteor was less bright in the middle than at the beginning and end of its flight It was moving from left to right

Such of the Meteors as reach the Earth are of low velocity and belong to streams overtaking our globe They usually have long horizontal flights The swifter class of Meteors are dissipated in the higher atmosphere, so that fragments of the August Perseids or November Leonids have never fallen to the ground The very slow Meteors (the Andromedids of November) appear to have yielded only one certain instance (November 27, 1885)

Notwithstanding the great number of Comets and of Meteoric Systems observed, there are not many striking and thoroughly proven instances of identity or accordance There are, however, a fair number where the facts suggest, if they do not prove, absolute agreement, and in the table of twenty on page 440 the abbreviation

" A " means accurate or accepted agreement, while

" P " refers to probable or possible ones

Except in one instance the observations were made at Bristol

In former times, when little was certainly known about Meteoric phenomena, and when incorrect views prevailed as to their meaning and influences, it is not surprising that people were often alarmed at unexpected visitations of fireballs, or falling meteoric stones, or metal One of the ancient Emperors had a sword forged out of a mass of meteoric iron which fell in his dominions, and this was regarded as a sacred and infallible weapon of defence It is considered probable by many that the "image that fell down from Jupiter," worshipped in the temple of Diana at Ephesus, was in reality a large Meteorite In the Seventh Century a stone fell which was built into the north-east corner of the Kaaba at Mecca, and afterwards worshipped by the Moslems One of the most remarkable incidents of this nature occurred at Ensisheim, in Alsace, on November 16, 1492, at noonday, when a Meteorite of 260 lbs weight fell with loud detonations like thunder

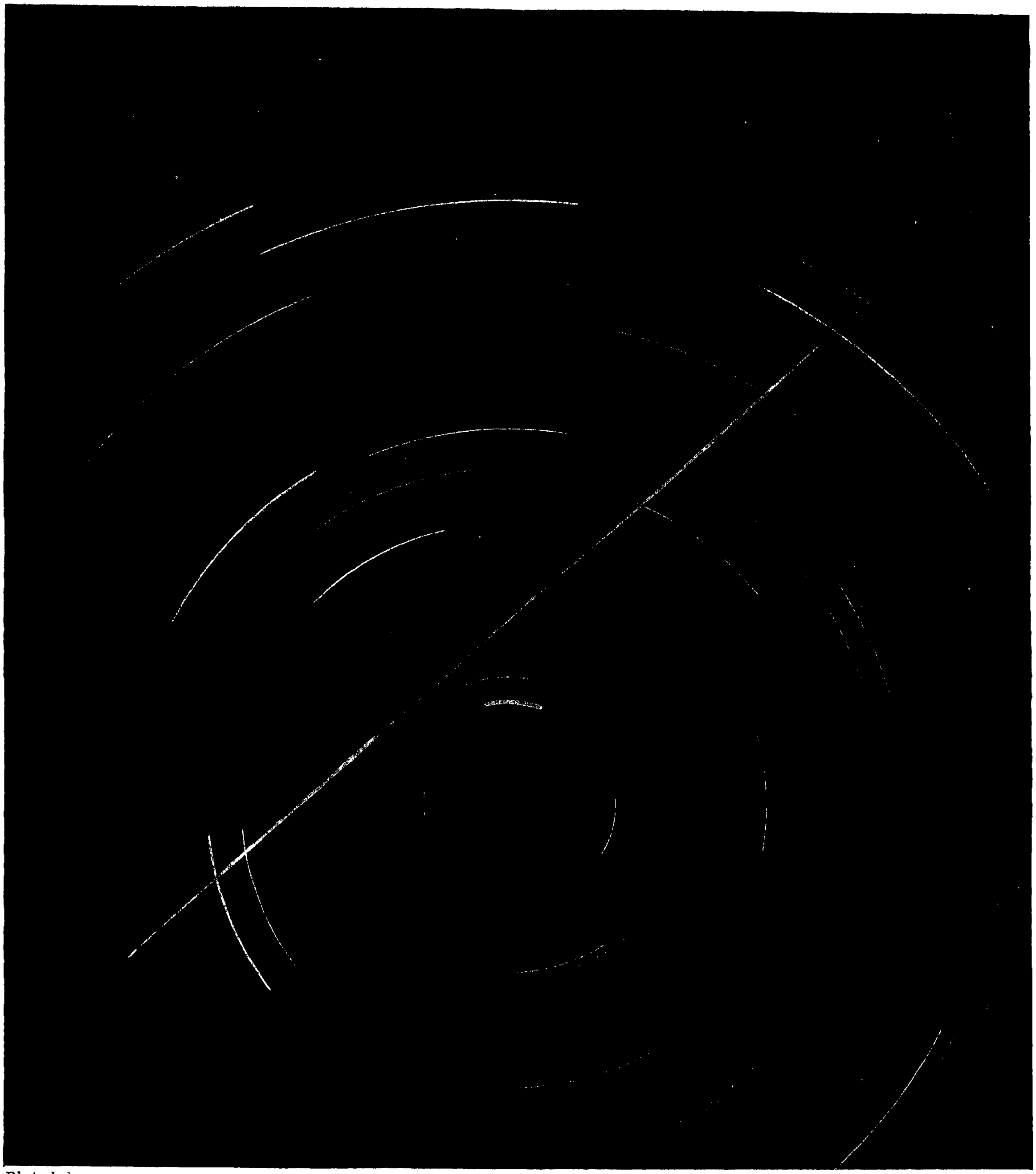
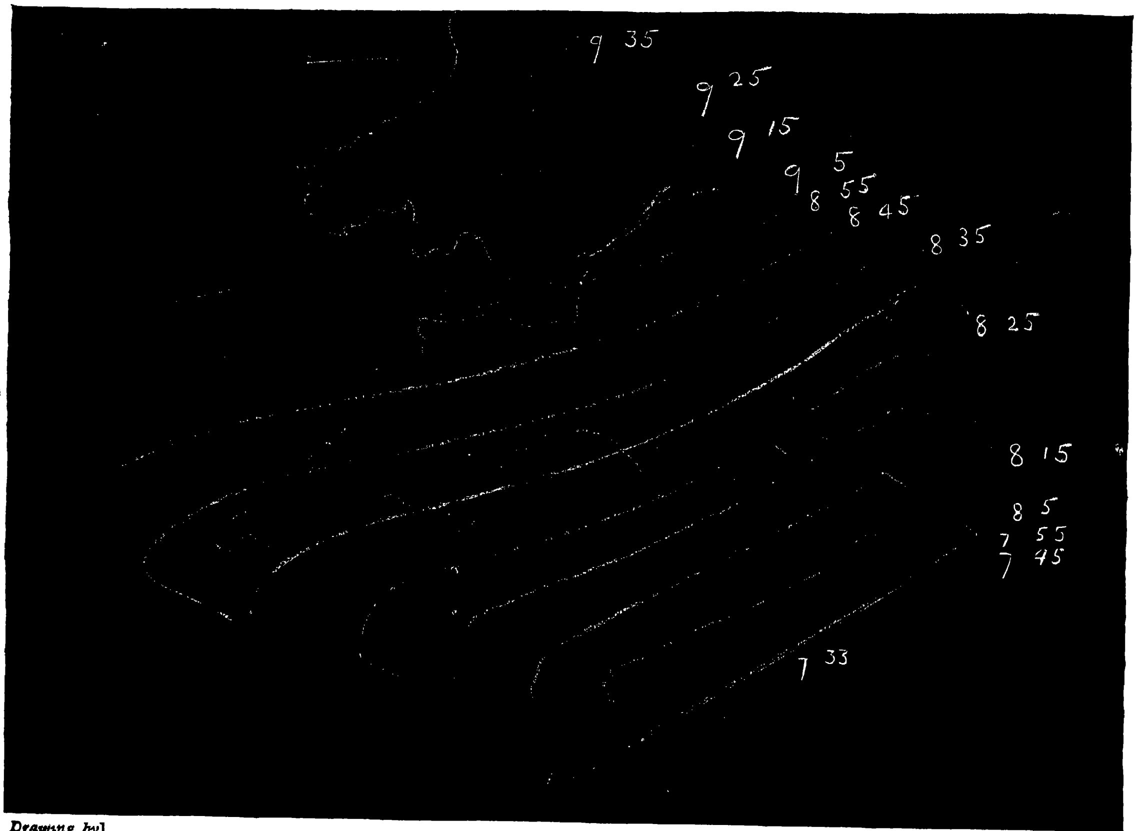


Photo by] [*W J S Lockyer*

PHOTOGRAPH OF A BRIGHT METEOR

This is one of the finest photographs of a meteor ever secured, and was taken at Sidmouth on 1922, November 16 The camera used was pointed towards the Celestial Pole and the plate was exposed for two hours fourteen minutes During this time the rotation of the Earth caused the stars to leave curved trails, with their centres at the Pole The short bright trail just above this central point is that of Polaris It will be noted that the meteor was subject to marked fluctuations of brightness at different portions of its path It is believed to have originated from a radiant in Taurus



Drawing by] [*W F Denning*

THE DRIFT OF A METEOR TRAIL

On 1909, February 22, at 7 33 p m, a brilliant meteor passed in a south-west direction over the northern coast of France The luminous trail which it left in its wake persisted as a visible object for over two hours, during which time it drifted in a north-west direction at 120 miles an hour, under the influence of a violent wind in the upper atmosphere Our illustration shows the position and shape of the trail at intervals of ten minutes

ACCORDANCES IN COMETARY AND METEORIC RADIANTS

Comet	Date of Nearest Approach	Computed Radiant	Observed Radiant	Dates of Meteors
		α δ	α δ	
P 1746	Feb 25–Mar 8	33° + 33°	33° + 36°	Feb 20–Mar 1 (16 meteors)
P 1847 I	April 11	231° + 27°	231° + 27°	April 13 (Schiaparelli and Zezioli)
A 1861	April 20	270½° + 33°	271° + 33°	April 20–21 Many Lyrids
A Halley	May 4	337° 0°	337° − 2°	April 30–May 6 Many Aquarids
P 1618 III	June 10	273° 0°	273° − 1°	May 26–June 13 (14 meteors)
P 1781 I	June 14	338° + 57°	335° + 57°	June 10–28, 1887 (16 meteors)
P 1850 I	June 23	313° + 60°	312° + 61°	June 5–23 (17 meteors).
A 1921, Pons-Winnecke	June 25	219° + 55°	228° + 54°	June 28, 1921 (7 meteors)
P Brooks	June 28	15° + 29°	16° + 30°	July 1–30 (24 meteors)
1822 III	June 30	342° + 11°	343° + 12°	July 9–13, 1921 (21 meteors)
P 1770 II	July 13	349° + 12°		
P Lexell	July 8	276° − 21½°	282° − 24°	June 8–29 (14 meteors).
P Morehouse	July 5	4½° + 28°	3° + 27°	July 6–17 (15 meteors)
P Denning	August 4	303° − 10°	303° − 10°	July 21–August 6 (51 meteors)
A 1862 III	August 10	44° + 57°	44° + 57°	August 10–12 Many Perseids.
P 1871	August 20	3° + 47°	6° + 46°	August 20–25 (14 meteors)
P Daniel	Sept 12	347° + 3°	346° + 2°	Sept 8–17 (26 meteors).

ACCORDANCES IN COMETARY AND METEORIC RADIANTS—*cont*

Comet	Date of Nearest Approach	Computed Radiant α δ	Observed Radiant α δ	Dates of Meteors
P 961	Sept 13, 27	62° − 13°	61° − 11°	Oct 23–Nov 4 (7 meteors)
1580	Oct 16	61° − 17°		
P 1842 II	Oct 21	81° + 57°	78° + 57°	Oct 14–20 (35 meteors)
P 1739	Oct 22	157° + 39°	155° + 40°	Oct 16–22 (18 meteors)
P 1582	Nov 9	89° + 36½°	86° + 34°	Nov 9–12 (33 meteors)
A Tempel	Nov 13	150½° + 23½°	150° + 23°	Nov 11–15 Many Leonids
P 1784 I	Nov 20	146½° − 18°	148° − 12°	Nov 13–15 (Suspected)
A Biela	Nov 27	25° + 42½°	25° + 43°	Nov 27, 1872-85 Many Andromedids
P Perrine	Nov 29	298° + 26°	302° + 24°	Dec 1–9, 1917 (12 meteors)
P Pons	Dec 6	200° + 68½°	204° + 69°	Dec 8, 1884 (18 meteors)
P Mechain-Tuttle	Dec 20–21	220° + 76°	218° + 76°	Dec 21 (7 meteors)

In addition to showers of Falling Stars, there are showers of Stony Meteorites These occurrences represent the break up of a large Meteor, and its distribution (when it falls) over a considerable area But occasionally it may well represent a cluster of Meteors, for these bodies sometimes travel in multiple fashion and when disintegrating may throw their unconsumed fragments over an elliptical region having nearly the same line of direction

On April 26, 1803, at L'Aigle, France, between 2,000 and 3,000 stones fell and created consternation among the inhabitants of the district On May 22, 1808, at Stanwern, Austria, about 200 stones descended, but this was trifling to certain other experiences

On January 30, 1868, at Pultusk, in Poland, and again on February 3, 1882, at Mocs, Hungary, about 100,000 small stones fell As recently as July 19, 1912, a cloud of about 14,000 stones fell in Arizona

The surprising nature of these novel events may well be imagined, for people are not prepared for and rarely understand the meaning of such strange and startling visitations On December 17, 1917, a Meteorite fell at Perth, Scotland, after breaking into four pieces, with a thunderlike noise, and this represents a similar event, though on a more limited scale, to those previously narrated

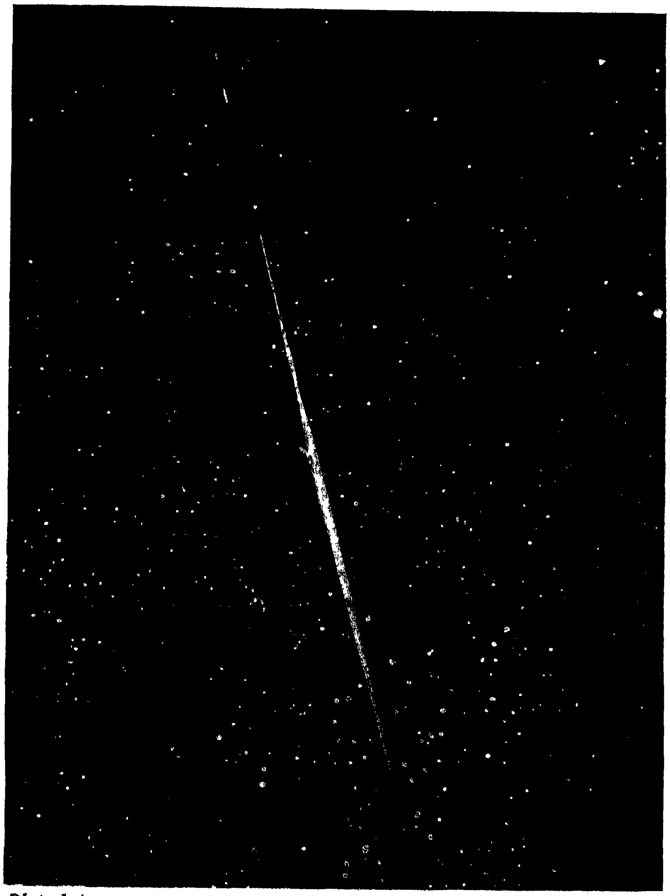


Photo by] *[E E Barnard*

PHOTOGRAPH OF A METEOR IN FLIGHT

Photography gives an accurate idea not only of the apparent position of a meteor's path in the sky, but also of the relative brilliance of the body at various stages in its flight In the photograph above the waxing and waning of the meteor's brightness is clearly shown, and also two short revivals of incandescence at the end of the path, near the top of the picture

Drawing by] [*W H Steavenson*

A "CORKSCREW" METEOR TRAIL

This trail, left by a bright meteor on 1916, July 26, persisted long enough to allow of its examination with a large telescope It was then found to be of helical, or "corkscrew" structure, a quarter of a degree in thickness and composed of "waves" one degree long Many meteors describe paths of this kind owing to the action of atmospheric resistance on their irregular shapes The same thing happens to artillery shells and is known in ballistics as "precession" Only a smooth spherical shell or meteor would travel in a perfectly straight path without rotation

A large Meteor, when rushing through the air, is heated to such an extent that it bursts with a loud detonation and then occasionally strews the countryside with its partly consumed debris

Falling stars exhibit great diversity in many respects Some remarkable instances of the largest kind, known as Fireballs, have been recorded, and a few of the most noteworthy may be summarised, as follows —

REAL PATHS OF NOTABLE FIREBALLS

Year	Date	G M T	Mag	Height Began	Height Ended	Path	Velocity	Radiant Point	No
				Miles	Miles	Miles	Miles per sec	α δ	
1676	Mar 31	8 5 p m	☽	174	38	250	2¼	215° + 17°	1
1719	Mar 19	8 15 p m	☽	80	60	175	5	295° + 45°	2
1783	Aug 18	9 15 p m	⊙	60	57	1,100	23	120° + 35° S	3
1850	Feb 11	10 4½ p m	> ☽	84	19	130	12	37° + 34°	4
1860	July 21	2 44 a m	> ☽	100	53	1,000	10	161° + 16°	5
1868	Sept 5	9 10 p m	—	103	67	880	38	18° − 8°	6
1868	Oct 7	11 50 p m	⊙	100	32	99	14	330° + 20°	7
1868	Nov 3	3 17 p m	⊙	70	25	77	26	220° + 16° S	8
1869	Nov 6	6 50 p m	> ☽	90	27	170	35	62° + 37°	9
1877	Nov 23	8 24 p m	> ☽	96	14	133	17½	62° + 21° D	10
1889	May 22	10 8 p m	♃	50	58	292	14	63 + 35°	11
1894	Feb 8	0 28 noon	—	80	20	—	—	Hercules S	12
1894	Jan 25	10 1 p m	☽	89	16	160	18	331° + 55° D	13
1896	Feb 10	9 30 a m	> ☽	—	20	—	—	SD	14

REAL PATHS OF NOTABLE FIREBALLS—*cont*

Year	Date	G M T	Mag	Height Began	Height Ended	Path	Velocity	Radiant Point	No
				Miles	Miles	Miles	Miles per sec	α δ	
1900	Jan 9	2 55 p m	> ☽	59	23	174	—	280 − 12° S	15
1902	Aug 22	2 2 a m	☽	65	33	611	15	283° − 10½	16
1909	Feb 22	7 33 p m	☽	56	50	155	25	196 + 20°	17
1911	Feb 19	9 22 p m	♃	70	49	590	14	46 − 15	18
1914	Feb 9	—	—	42	—	5,500	8	Pegasus	19
1914	Oct 13	8 46 p m	> ☽	29	0	49	8	348 + 3° D	20
1917	Dec 3	1 15 p m	> ☽	64	0	86	—	302 + 21° SD	21
1922	Feb 7	3 55 p m	> ☽	56	32	82	14	60° − 11° SD	22

5—Corrected for zenithal attraction radiant is at 118° + 3°, (" zenithal attraction " refers to the amount of displacement of the radiant due to the earth's attraction)

10—The detonation equalled the noise of a hundred 100-ton guns (Tupman)

14—The streak remained visible five and a half hours

17—Streak remained two hours and drifted to N W 120 miles per hour

19—A swarm of large Meteors, Path 5,500 miles and the longest ever known, flight parallel to Earth's surface over nearly all this track

20 and 21—Fell to the earth

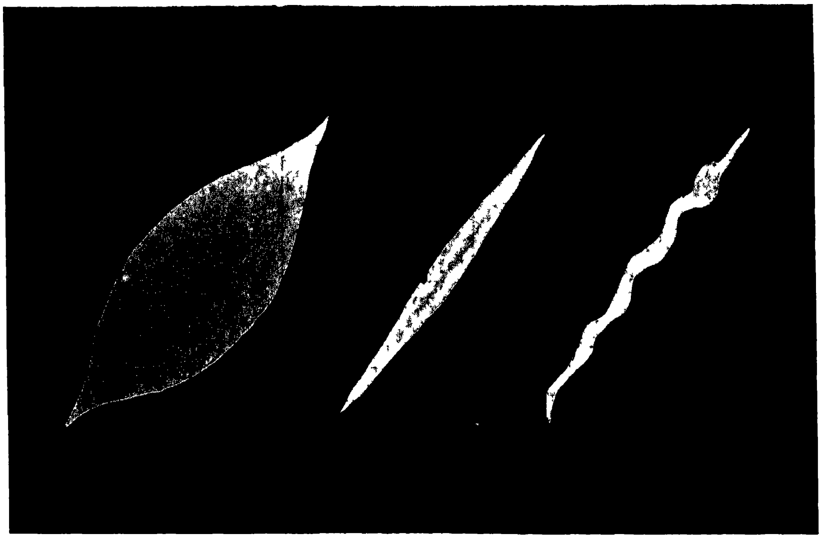
In column four > means " brighter than," ☉ the Sun, ☽ the Moon, ♃ Jupiter

" S " in the ninth column means " in sunshine ", " D " that the fireball detonated

The largest kinds of Fireballs constitute one of the grandest splendours of the heavens Even in the day-time, when sunshine dominates sky and Earth, a Fireball may suddenly come out of the blue with a brilliant flash ending its glories and a thunderlike detonation following to signify the disruption and destruction of the object At night, when there is no Moon and the heavens are thickly studded with stars, then the Fireball may display its striking illumination of sky and landscape, and startle the spectator with the vividness of its intensity Sometimes there are several flashes, due to unequal ignition, for at certain points along the streaming flight the object

METHOD OF PHOTOGRAPHING METEORS

The securing of meteoric photographs is largely a matter of chance, as it is impossible to be certain when and where a bright meteor will appear When a shower is expected a number of cameras with rapid lenses may be set up to point in slightly different directions, to cover a large area of the sky The observer sits close at hand and records the time and rough position of any bright meteor seen, and it can afterwards be identified on the photographic plate



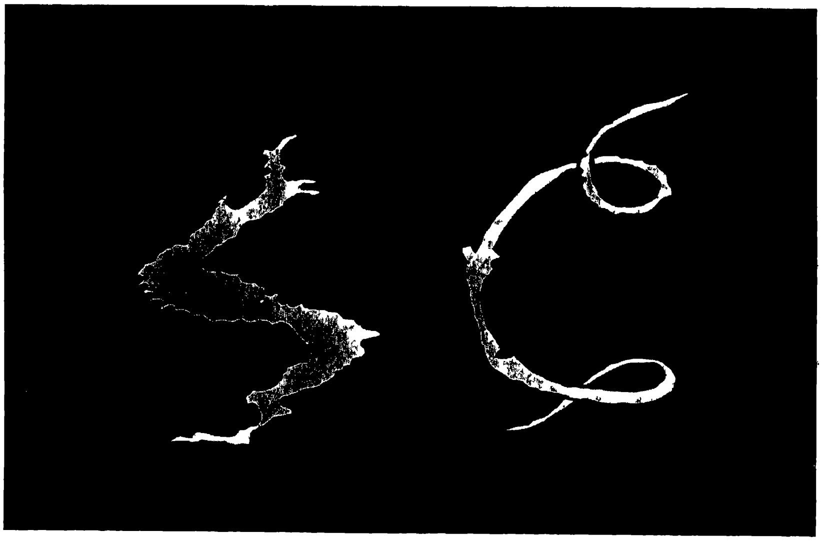
A METEOR TRAIL

Very bright meteors leave luminous trails in the path of their flight, and these in some cases persist for some time before fading into invisibility The trails are generally faintest at their edges, which are the first parts to disappear, causing an apparent narrowing as in the three stages shown above

blazes up and leaves brighter sections in the train where the outbursts occurred

These Fireballs should be always recorded in detail, and particularly their apparent paths in the firmament, for if the data are immediately available for the computation of the height and direction it may be easily possible to indicate the place of fall and thus, in cases where the object reached the Earth, enable a search to be made In the instance of the Yorkshire Meteorite of October 13, 1914, the locality of its probable descent was indicated by the present writer, and the object was accidentally discovered at the spot predicted

Autumn nights are often prolific in these luminous appearances, but they come at all times, and are sometimes so brilliant as to shine in the day-time, and to offer a momentary splendour almost equal to if not exceeding that of the Sun But we cannot foretell the times of their individual apparitions They burst out suddenly, it may be in the twilight of early evening, in the glare of moonlight, or with fog or thin cloud partly veiling the stars, but best of all, of course, they are displayed in a clear, moonless sky



A DISTORTED TRAIL

When a meteor trail is bright enough to persist for several minutes it is often observed to drift slowly from its original position and to become bent or twisted in outline This is the result of currents of wind in the higher parts of the Earth's atmosphere The two sketches above were made ten minutes apart

When a bright falling star is seen, the observer should endeavour to notice its chief features and its exact place amongst the stars If he is unacquainted with the constellations, he should estimate the bearings of the beginning and end points, and give the altitudes as nearly as possible, he should also note the duration of flight In the event of a train or streak remaining after the head has vanished, it should be carefully watched and the extent and direction of its drift amongst the stars ascertained as exactly

as possible These meteoric trains and streaks furnish valuable evidence on the air currents operating in the upper strata of the atmosphere The trains are usually between fifty and sixty-five miles above the Earth's surface, and are often carried along at a velocity of about 120 miles per hour Not infrequently they continue visible during several minutes and in exceptional cases remain for much longer periods The glowing residue of a fine Meteor which appeared on February 22, 1909, remained in view for two hours, and drifted in a north-west direction at a hurricane rate

Careful observations of Meteors and Falling Stars are valuable, and likely to increase our knowledge of a very interesting branch of Astronomy These bodies forming, as it were, the dust of the universe and the messengers from distant space, may be regarded as the connecting links between our Earth and other planetary worlds As such, therefore, they deserve our sympathetic interest, while their transient glories exhibited in the sky must always awaken keen appreciation

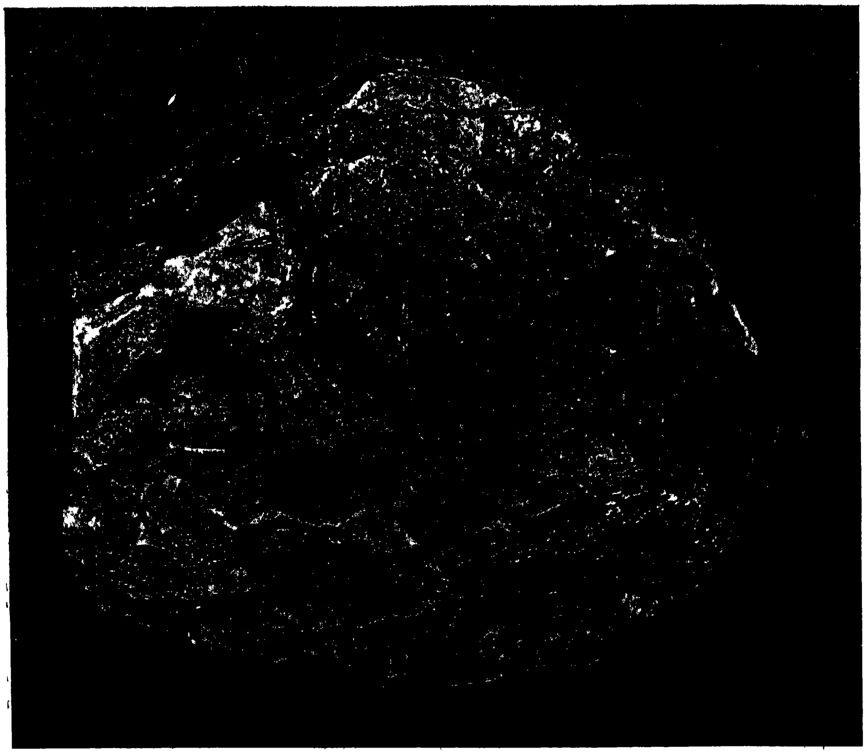
There may be a night without a visible Moon, but there is never a night without a Falling Star unless, indeed, the firmament is veiled with clouds Unceasingly they are showered into the Earth's atmosphere, and it is fortunate that it has the power to destroy them nearly all

Only those who have occupied themselves considerably in the work can realise the attractiveness of Meteoric observation Others who are fresh to the study and lacking experience can hardly appreciate the pleasure which the habitual observer feels in its pursuit A man who gazes at the stars occasionally and sees Meteors falling amongst the constellations in an indiscriminate fashion cannot properly record the picture and must fail to comprehend its meaning One however who has acquired a knowledge of the subject can interpret the details and read something of the story of nearly every Meteor that falls He can tell the particular shower to which it belongs, and can

[J H Shepstone

A STONY METEORITE

Many meteorites are not mainly metallic in composition, but contain large quantities of silicates, and other stony substances They are less heavy, bulk for bulk, than the metallic meteorites and have a rougher surface They are sometimes referred to as "uranoliths," to distinguish them from the iron meteorites



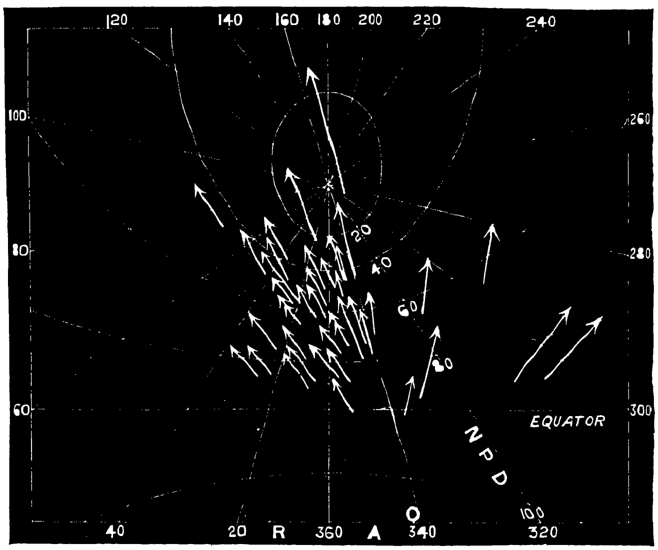
THE OTUMPA METEORITE

This is an example of a meteorite whose substance is mainly metallic The surface is comparatively smooth and shiny, and of a dark blackish brown colour Meteorites which, like the one above, are composed very largely of iron, are termed "siderolites" The one above weighs 1,400 lbs

locate its radiant point from its duration of flight and aspect He can pretty correctly estimate the height of the object and perhaps knows, and may have seen, the parent Comet from which it had its origin

To witness a shower of shooting stars is more interesting when the observer knows the Comet which supplies it This is, however, not always possible The great displays of August and November are connected with and directly occasioned by well-known Comets There are also May and June showers derived from the Comets of Halley and Pons-Winnecke, and the pleasure of awaiting and seeing the Meteors is accentuated by this circumstance Having perhaps viewed the Comets themselves we naturally feel curious to see their offspring in the Meteors In fact, our knowledge of a little of their life history intensifies the attractions they visibly present to the eye It is like a person who looks up to the stars and can recognise the constellations and call the chief stars by their names His acquaintance with them makes him re-regard them as old friends, and thus the contemplation of the familiar face of the heavens often brings him an impressive satisfaction

Meteoric Radiants and Comets.—Several mathematicians have investigated the ecliptical Meteoric radiants and found that they may be of lengthy duration with little apparent change in the radiant points This is what observation



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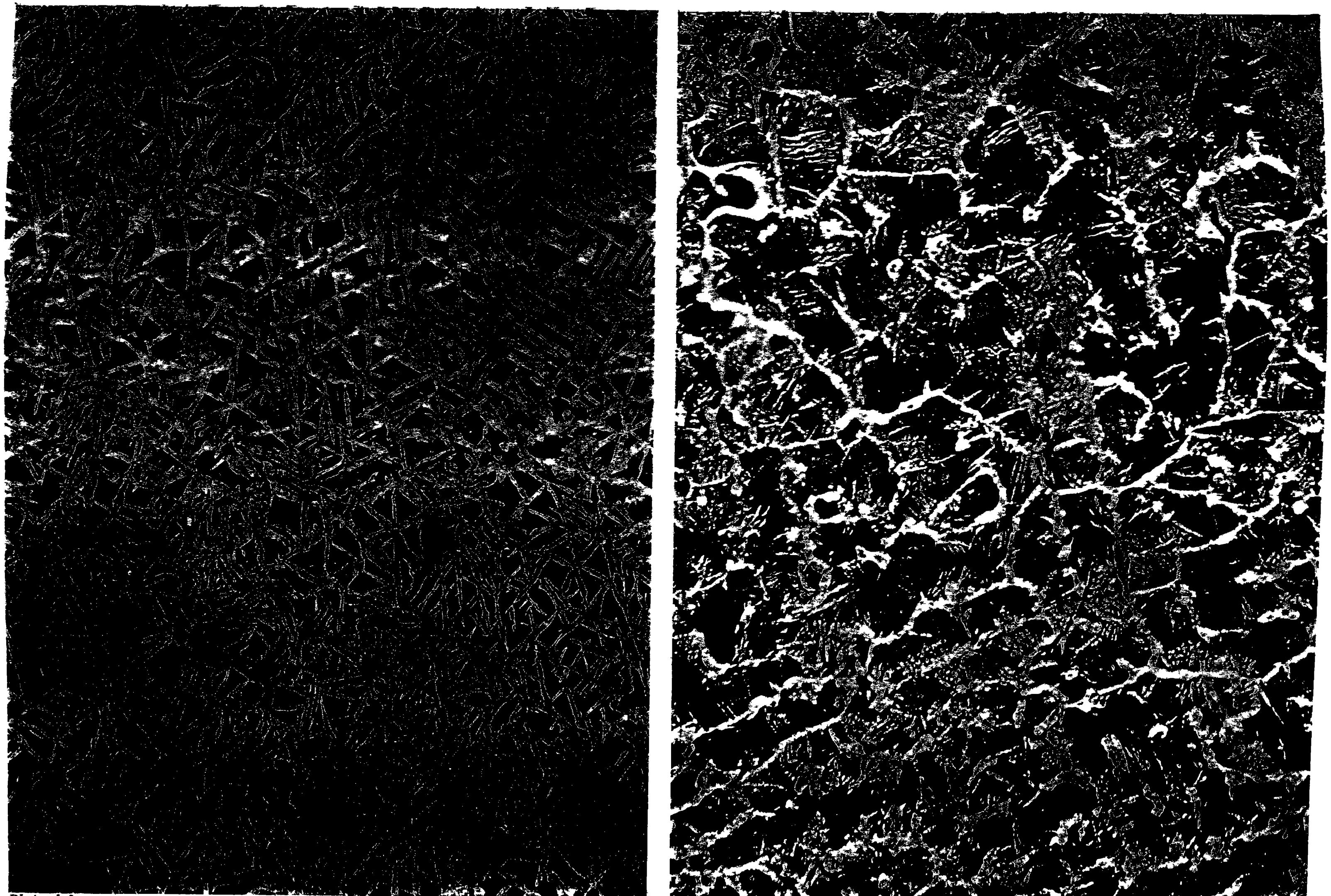
RADIANT OF METEORS, JULY 27–29

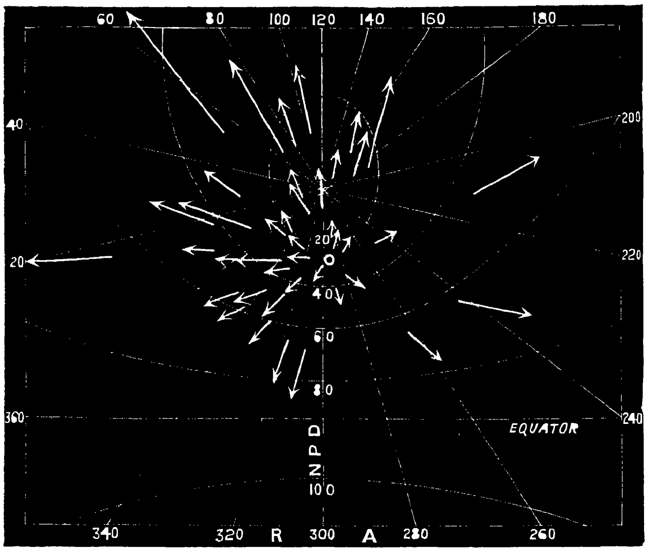
A radiant is less easily determined if placed so low in the sky that its meteors can only be seen on one side of it The apparent shortness of meteoric paths near to the radiant point is an effect of foreshortening, since these meteors are coming almost directly towards us This is better shown in some of the other diagrams



Photos by] [*P. Primrose*

METEORIC METAL

These photographs show sections cut through portions of metallic meteorites to show their structure. That to the left is a polished section of meteoric iron, enlarged about three and a half times, showing Widmannstätten figures indicative of very slow cooling of the nickel iron minerals present. The photograph to the right is nickel iron metabolite, magnified a hundred and thirty times, showing the result of heating in passing through the air. In the case of large meteorites, it is only the superficial parts that are strongly heated, owing to the short time of exposure to atmospheric friction. Sections such as the above, therefore, vary according to the portion of the body from which they are taken



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RADIANT OF METEORS, AUGUST 21–23

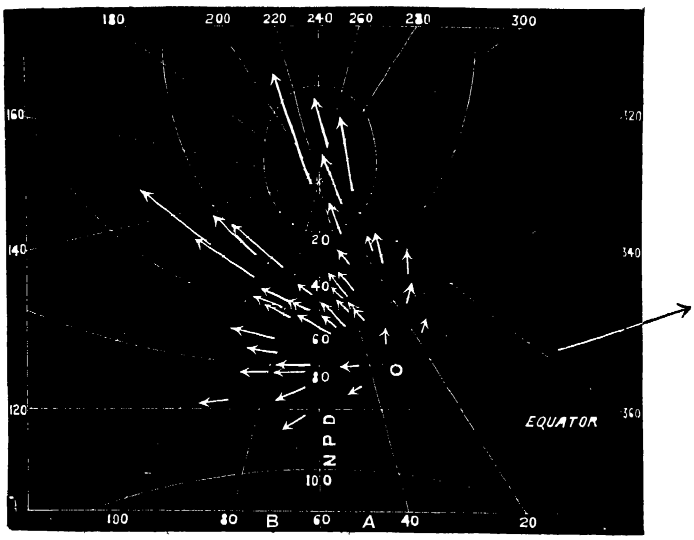
The arrow-headed lines represent the lengths, positions, and directions of the paths of meteors as actually seen in the sky Slight errors of observation are inevitable, but the radiant point can be fixed with considerable accuracy if a sufficiently large number of meteors is observed

had already proved, and there is no doubt that certain long continued showers directed from positions on or near the ecliptic can be identified with Comets whose orbits lie comparatively near that of the Earth

Lexell's Comet of 1770, or its debris (for the Comet seems to have ceased to be visible), showers Meteors from a radiant at about 282°–25° in June, July, and August Denning's Comet of 1881, yields Meteors at end of July and first half of August from 303°–10° In the latter case the computed distance between the cometary orbit and the Earth is rather considerable (0 1 = 10 millions of miles), but this does not vitiate the accordance, as the cometary material may be distributed over a considerable space

Daniel's Comet of 1907, whose orbit is within about six and a half millions of miles of the Earth on September 12, appears to have originated the shower of bright Meteors from 347° + 2°, which is visible from about August 25 to September 27 Zanoth's Comet of 1739 has yielded the Meteors from 154° + 40° often observed during last half of October and onwards through November and first half of December Other cases might be cited but no useful purpose would be served by unduly multiplying the evidence, suffice it that the writer is preparing a table wherein will be exhibited a number of comparisons suggestive of close relationship between certain cometic and meteoric orbits This is a highly interesting section of Meteoric Astronomy and has not been sufficiently cultivated and investigated since the late Professor A S Herschel devoted himself to its study

It is much to be hoped that recruits will be forthcoming not only for the theoretical investigation of the various problems presented by meteors, but also for their practical observation Additional workers are greatly needed in various departments of Astronomy, but in none more so than in this branch And here is a field in which, without incurring the expense of costly apparatus, work of high value may be accomplished, all that is required being a good view of the sky, the ability to make accurate observations, and such a measure of patience and enthusiasm as will enable the observer to maintain his vigils through the long hours of the night



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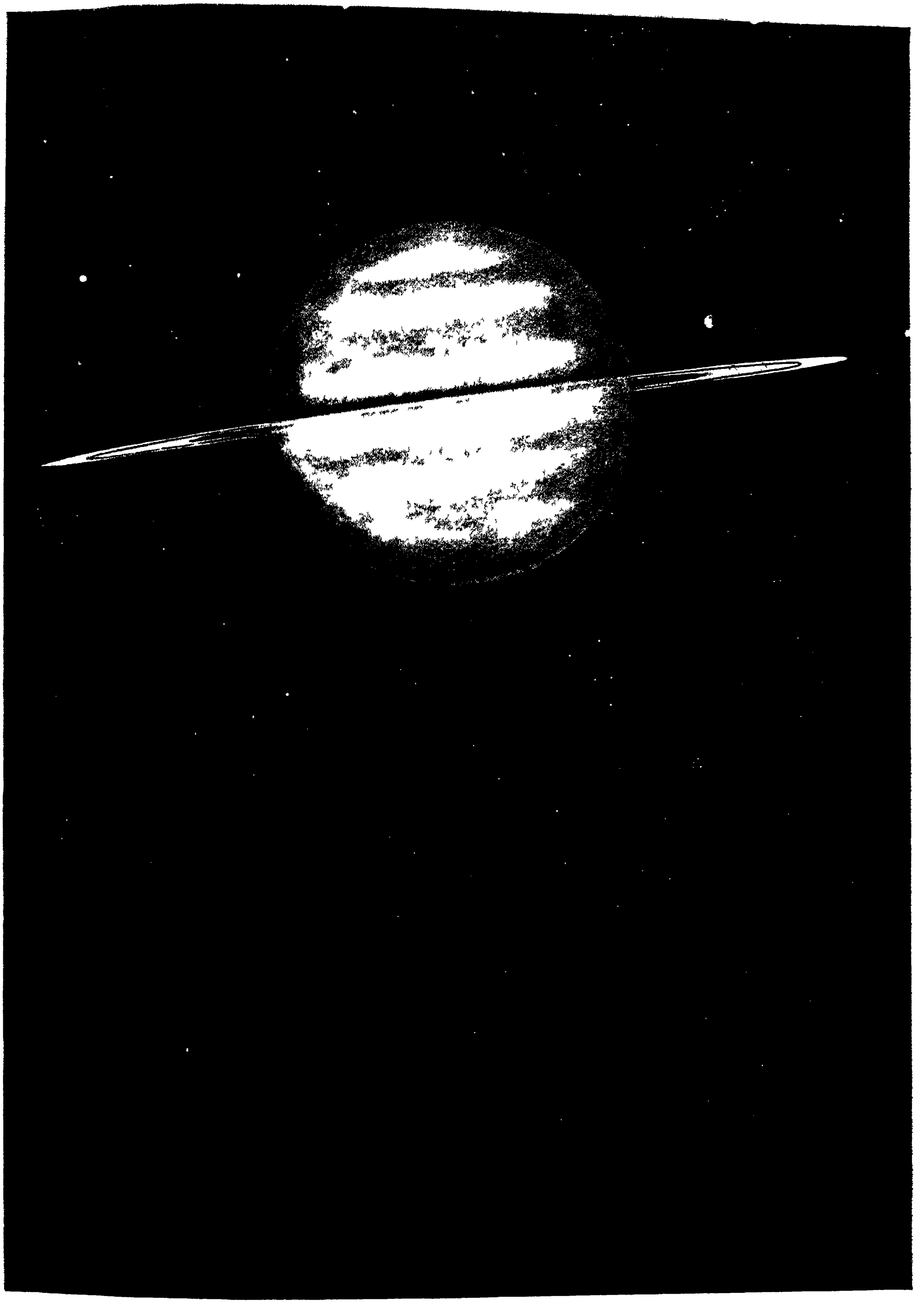
RADIANT OF METEORS, OCTOBER 15

The paths of meteors are best recorded on charts drawn (like the one above) on the "gnomonic" projection On such charts all lines observed as straight in the heavens are still straight, in spite of being now seen on a flat surface



THE PLANET SATURN

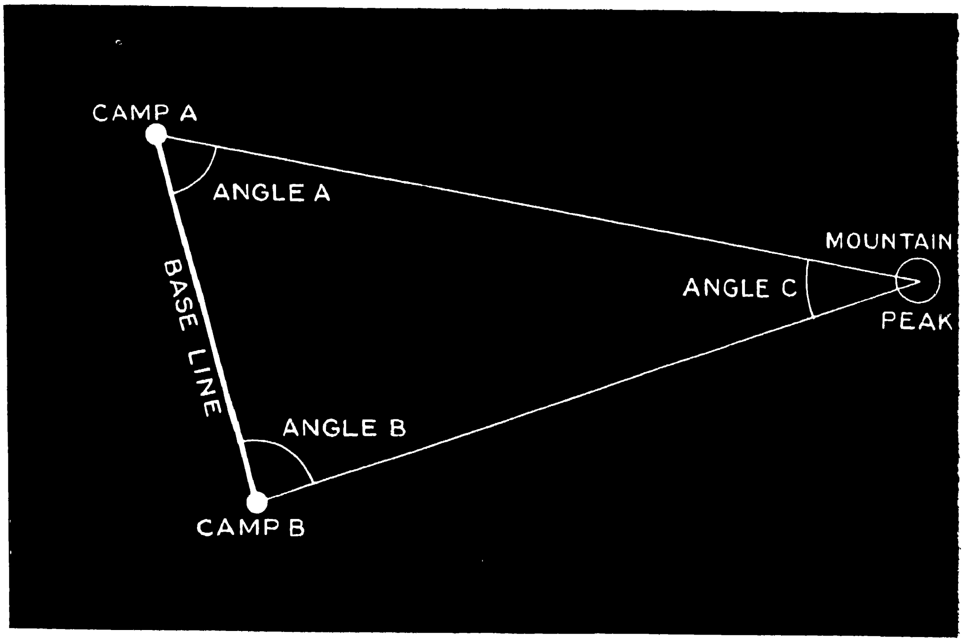
This illustration conveys a rough idea of the probable appearance of Saturn as seen with the naked eye from one of his satellites. The orbits of the latter lie nearly all close to the plane of the rings which therefore are seen almost edgewise. From one of the inner satellites they would appear even more narrow and linear than depicted above. The globe of the planet is delicately coloured and generally exhibits a series of parallel dusky belts. The rings are almost pure white in colour. (See Chapter VIII.)

CHAPTER XI

FINDING THE SCALE OF SPACE

By Peter Doig, F R A S

IN any science one of the most important requirements is the determination of numerical values Astronomers have to face what seems at first glance an insuperable problem of this kind—the ascertainment of distances to which it is impossible by the nature of things to apply measuring gauges directly The very earliest " watchers of the sky " believed all celestial objects to be situated at the same distance on the vault of the heavens, but the Greek thinkers began to assign relative distances to the Sun, Moon, planets and fixed stars Aristarchus of Samos, who lived about 280 B C., showed that the Sun must be at least nineteen times as far off as the Moon, which estimate is much below the truth, but was a step in the direction of positive knowledge beyond which there was no advance for a long time The scale of space was not then known even in the very roughest fashion, however, the first crude solutions of the problem were reserved for the later and possibly less acute intellects of mediaeval times, and that only for such less remote celestial objects as those in the Solar System



A SURVEYOR'S "TRIANGLE"

The surveyor who wishes to find the distance of an inaccessible point, such as a mountain peak, lays off and measures a base line between two camps From one camp he measures with his theodolite the angle between the mountain peak and the other camp, and then goes to his other station and does similarly for the first camp and the peak From these two angles and the measured length of the base line, the distances of the peak from the two camps can be easily calculated

The process of finding the distance of a celestial object is essentially the same as is used by a surveyor when he desires to find the distance of some inaccessible object such as a mountain In most cases measurement in the ordinary way with tape or chain is impossible because of the roughness of the intervening country, or because of the impossibility of attaining to the top of the mountain. For example, the summit of Mount Everest is as yet inaccessible, but its distance from a hill station, such as Darjeeling, can be found with great accuracy The surveyor proceeds as follows

From a camp at A the distance is first accurately measured off to camp B, the line between being described as the " base line " Setting up his theodolite at A he measures the angle between the camp B and the mountain peak and then goes to camp B and measures the angle B similarly He then knows the length of one side of the triangle and the sizes of two of its angles, and by a very simple calculation

can derive the third angle C and the distances from camp A or camp B to the mountain The surveyor does not concern himself directly with the angle C but deals with distances so that he can "triangulate" an entire territory

By a sustained process of connected triangles and accompanying astronomical observations for longitudes and latitudes, much of the Earth's surface has been mapped out and the shape and dimensions of our globe closely ascertained As is well known the shape of the Earth is not truly spherical, but of a flattened spheroidal form, so that the diameter from pole to pole is 7,900 miles and across the equator 7926 7 miles

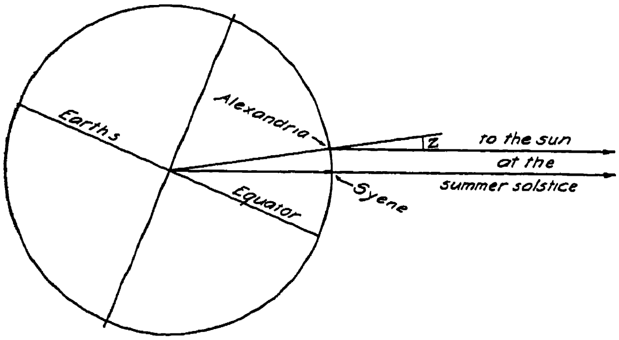
From] ["Adolfo Stahl" Lectures

THE WELL OF ERATOSTHENES

This well, situated at Assouan (the ancient Syene) is said to be the one used by Eratosthenes in connection with his famous measurement of an arc of the meridian From his observations he obtained the first reasonably correct value for the Earth's circumference and diameter

The surveyor finds a base line of several hundred yards sufficient for determining most distances, but occasionally uses one as long as possible, of several miles length, so as to obtain an accurate measurement of a very remote object The astronomer, however, requires a very much greater base line for the smallest of celestial distances The nearest of the heavenly bodies is the Moon, of which the mean distance is 238,860 miles, and for the determination of the size of this great gap the astronomer finds a base line in the Earth itself In this case there are two observatories, the distance between which is well known The angle at the Moon and the sides of the triangle can be well determined and from them the distance between the centres of the Earth and Moon The "parallax" of the Moon is half the angle which is contained between the lines connecting the extremities of the Earth's diameter and the centre of the Moon and is somewhat less than one degree (fifty-seven minutes approximately)

The same base line is used in finding the scale of the Solar System As the diameter of the Earth is but 7,900 miles, we cannot get a longer base than that, and practical considerations limit it to about 7,000 miles The Sun is more than 13,000 times this distance away and the triangle concerned is extremely long and narrow, with the angle at the Sun smaller than sixteen seconds of arc As a problem of surveying, the measurement of distance by direct observation of the Sun's position in the sky is not capable of more accuracy than about one part in thirty or forty



From] ["Adolfo Stahl" Lectures

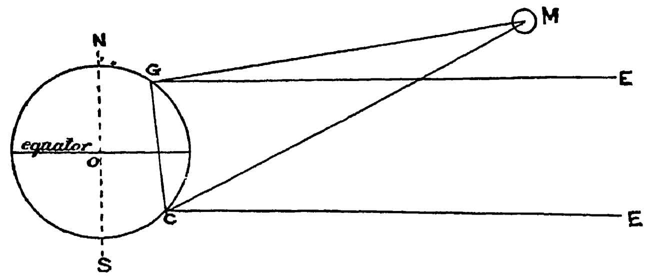
AN ANCIENT MEASUREMENT OF THE SIZE OF THE EARTH

This diagram illustrates the method employed by Eratosthenes Observations of the Sun's altitude at Alexandria and Syene respectively gave the number of degrees of latitude (shown by the angle Z) between the two places The actual distance being known in units of linear measure, it was easy to calculate the length of the complete 360° comprising the Earth's circumference

If the stars could be observed close up to the Sun and simultaneous observations made of its apparent position among them as seen from the ends of our base line, the problem would be simple and capable of considerable accuracy with little effort The Sun would appear differently placed with reference to the vastly remoter stars, a nearer body having a shift (Greek, "parallaxis")

relative to objects farther away We cannot see stars close up to the blazing disc of the Sun owing to the overwhelming atmospheric effect of its radiance, but on rare occasions the planet Venus passes across its face and at these times has a parallax relative to the Sun's disc

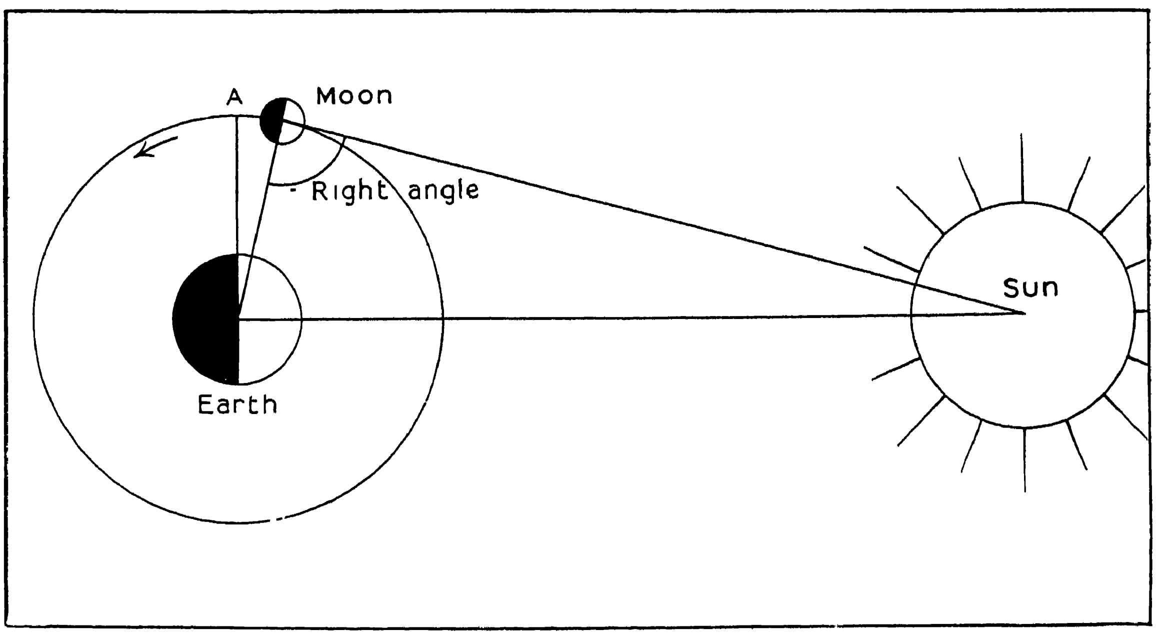
Two observers on the Earth at *a* and *b* (*see* page 452), will see the planet projected on different parts of the Sun's disc The observer at *b* will see the planet cross along the line CD, while the observer at *a* will see it traverse the Sun's face along the chord FG When Venus is between the Earth and the Sun (in "inferior conjunction") its distance from the Sun is to its distance from the Earth in the proportion seventy-two to twenty-eight This is known from the law discovered by Kepler, which states that the cubes of the distances between the planets and the Sun are proportional to the squares of their periods of revolution about him, and it was discovered by that great astronomer independently of any knowledge of the actual distances



MEASURING THE DISTANCE OF THE MOON

This diagram shows a method of measuring the distance of the Moon G and C represent two observatories (say Greenwich and the Cape of Good Hope) M is the Moon, GE and CE are the directions of the equator on the sky at the two places The difference of the angles MCE′ and MGE, which is the same as the angle GMC, is measured and from this angle together with the known rectilinear distance GC, the distance of the Moon is derived, just as by a surveyor in the case of an inaccessible terrestrial object

The base line or rectilineal distance between *a* and *b* is known, and as the ratio between this and the line *xy* is twenty-eight to seventy-two, *xy* can be computed The ratio of the lengths of the chords CD and FG is got from the observed time of crossing of Venus across the Sun and it is then possible to calculate the size of the Sun's disc itself by means of the known distance *xy* The angular diameter

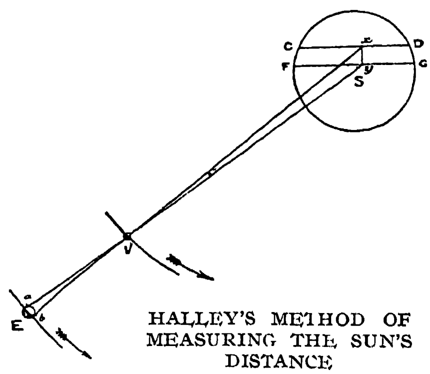


"PHASE" METHOD OF MEASURING THE SUN'S DISTANCE

An ingenious method of measuring the Sun's distance in comparison with that of the Moon was devised by Aristarchus (B C 280) In the above diagram (not to scale) the Moon is shown at the instant it would look half Full from the Earth The angle at the Moon must then be a right angle Aristarchus estimated that the First Quarter of the Moon was about twelve hours shorter than the Second Quarter, so that the Moon was six hours in going to A, or about four degrees of its orbit From this he deduced that the distance of the Sun is about nineteen times that of the Moon, which is much too small, the method failing badly because of the mountainous character of the Moon's surface, making it impossible to estimate accurately the instant when the Moon is half Full

of the Sun is measured, and to find its distance from the Earth we have simply to calculate the distance at which a body of known size subtends a given angle

Certain corrections have to be made for the motion of the observers at *a* and *b* due to the Earth's movement in its orbit and to its rotation The method described is due to Halley (1656–1742) who suggested it at a time when it was impossible that he should live to see it carried out Another method used on the occasion of a transit of Venus was suggested by Delisle (illustrated on page 205), but need not be further described, particularly as either method is no longer looked upon as a good one for determining the solar parallax Owing to various causes, chief among which is the so-called " black drop " and also a troublesome ring of light round the planet evidently produced by its atmosphere (*see* page 211), which render it almost impossible to estimate accurately the times of entry and exit of the planet on the solar disc, other methods are now more relied on In any case the method cannot be again applied until the year 2004, which sees the next transit of Venus

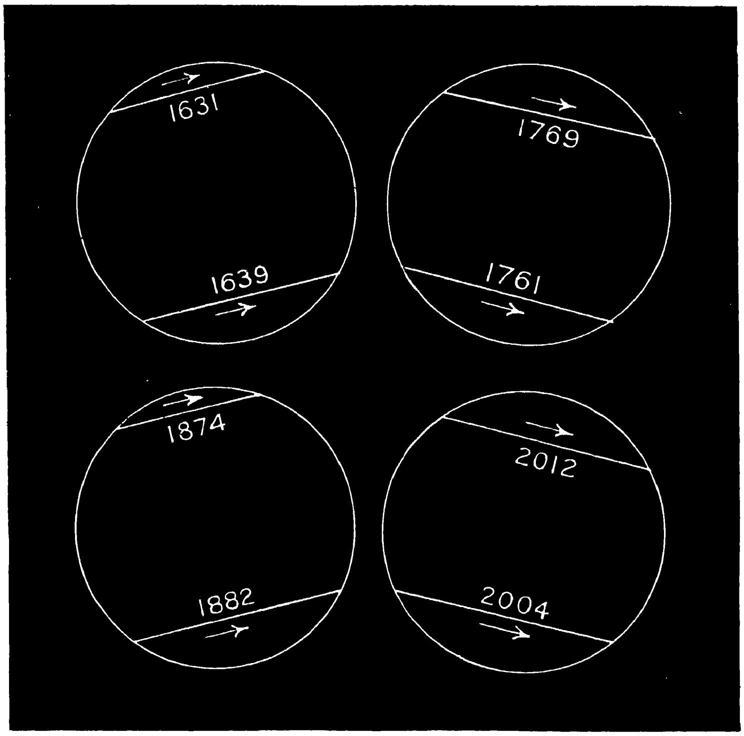


HALLEY'S METHOD OF MEASURING THE SUN'S DISTANCE

The diagram illustrates Halley's method of utilising the transit of Venus for measurement of the Sun's distance The observers on the Earth at *a* and *b* will see Venus cross the Sun's disc along the chords FG and CD respectively The relative length of these chords is got from the times taken in the transit The relative distances of Venus and the Earth from the Sun being known, and also the distance between *a* and *b*, the length *s v* can be computed and from that, and the ratio of the chords FG and CD, the actual diameter of the Sun is obtained The angular diameter of the Sun is measured, and to find its distance from the Earth we have simply to calculate the distance at which a body of known size subtends a given angle

Another method, which has been employed with great success and a higher degree of accuracy, depends upon the measurement of the parallaxes and distances from the Earth of some of the planets situated at greater distances from the Sun than the Earth By Kepler's Law above described, the dimensions of all the orbits of the planets in the Solar System are as a consequence derivable Mars and some of the minor planets or " asteroids " have been utilised in this way when at " opposition," *i e*, on the opposite side of us from the Sun and therefore crossing the meridian (due south) at midnight

The parallax of the planet observed can be determined in the same way as that of the Moon, either by observations at two distant observatories, or by a single observer who utilises his displacement by the Earth's rotation to provide a base line The actual measurements involved are the angular distances separating the minor planet from the background stars among which it is apparently



PAST AND FUTURE TRANSITS OF VENUS

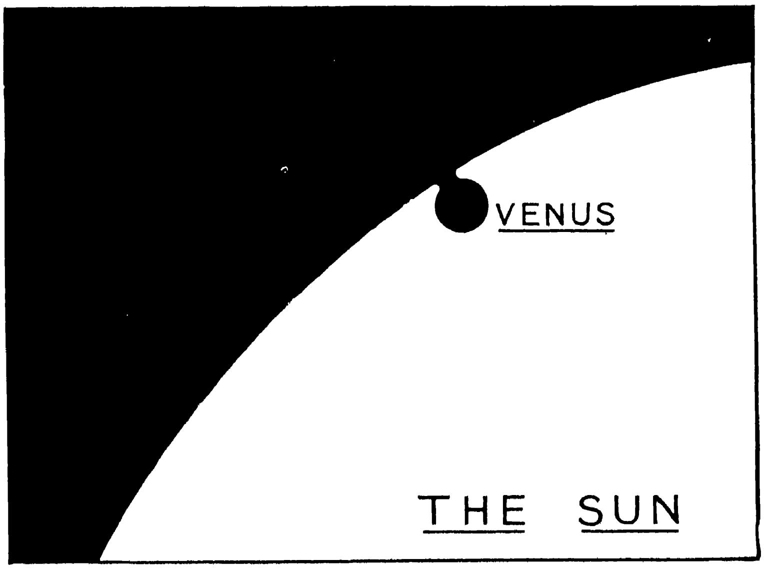
Transits of Venus occur in pairs, with eight years between each transit of the pair, and intervals of 105½ or 121½ years between the pairs The method of measuring the solar parallax by means of the transits was employed on the occasions of the Eighteenth and Nineteenth Century transits, but it is doubtful if those of the Twenty-first Century will be similarly utilised, as better methods are now known

situated These measurements have been made by an instrument called the heliometer, or by photography

The heliometer consists of a telescope which has its object-glass divided into halves along a diameter One half can slide along the other and thus produce two separable images By movement of the two halves the images of two stars can be superposed in such fashion as to give very accurate measurements of distance between them or between a minor planet and a star, the shift of the parts of the object-glass being regulated by finely divided screws, one turn of which is equal to a certain small angle on the sky

The great advantage of the photographic method, which is otherwise at least equally accurate, is that the astronomer is rendered much more independent of continued fine weather and clear skies A photograph can be made in two or three minutes, and with a comparatively short break in the clouds far more valuable material can be got than by a whole night's heliometer work, for the photograph once secured can be measured and discussed at leisure by day or during cloudy nights

The minor planet which is most valuable for this purpose is Eros, discovered in 1898, for which, although it is a very small body, probably not more than twenty miles in diameter, one would willingly barter the remaining hundreds of similar bodies This is because it moves in a very remarkable orbit (illustrated on page 76) lying for the most part within that of Mars, very eccentric (*i e*, departing largely from a circle towards an oval shape) and approaching the Earth on favourable occasions to within about 15,000,000 miles when it has a large apparent shift or parallax with reference to the background of fixed stars



THE "BLACK DROP"

It was expected by Halley that it would be possible to observe the instant of contact between the disc of Venus and the edge of the Sun within about a second of time Unfortunately, the formation of a "black drop" takes place instead of a round disc neatly touching the edge of the Sun, the time of real contact being doubtful by as much as ten or fifteen seconds

A close approach took place in 1900, but not until 1930 and 1937 will there be similarly favourable opportunities again The 1900 "opposition" was used to obtain the most accurate value for the solar parallax as yet derived By co-operation of a number of observatories using visual and photographic means a value of the solar parallax (or angle subtended at the Sun's distance by the Earth's semi-diameter) was obtained of

8 80 seconds of arc

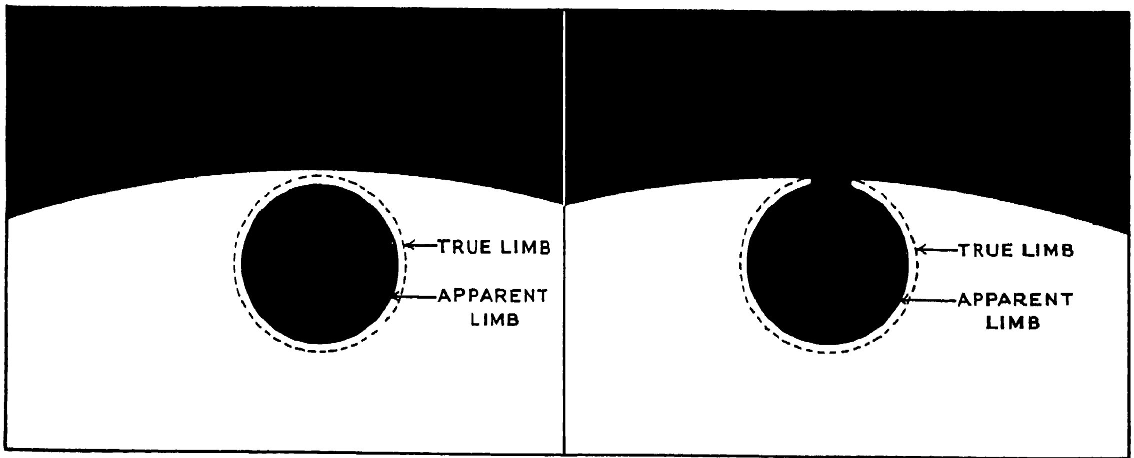
This corresponds closely to a mean distance of the Sun of 92,900,000 miles, which is probably correct within about 150,000 miles either way, according to very recent work, however, this parallax may be rather on the large side

There are reasons for believing, however, that the most accurate value of this fundamental constant of Astronomy will be obtained by other and less direct methods Some of these are of sufficient interest to be briefly referred to

One general method is by the disturbing effects of the planets' gravitation on each other's motions, or of the Sun on the Moon's movements Another depends on the mutual disturbances of the Earth

and Moon The Earth's centre revolves in a small orbit round the centre of gravity of the Earth-Moon system From the measured distance of the Moon and the ratio of its mass to that of the Earth, this orbit is found to have a radius of about 3,000 miles As a result of the Earth's motion in this small orbit the Sun appears periodically displaced to one side or the other in its apparent yearly circuit of the sky, from the place he would occupy if the Earth were not thus disturbed by the Moon The consequent angular displacement of the Sun having been measured, astronomers then learn the angle which 3,000 miles subtends at the Sun's distance, and from that can derive the distance by a simple calculation

Another way of measurement of the scale of the Solar System has been derived from observation of Jupiter and his family of moons When that planet is farthest from the Earth, on the other side of the Sun, there is an apparent delay in the times of the eclipses of his moons by the shadow of the planet compared with those occasions when the Earth and Jupiter are on the same side of the Sun, and therefore closer together by something like the width of the Earth's orbit This was an unexplained phenomenon until the Danish astronomer Romer suggested in 1675 that it was due to the time taken by light to travel over the additional space By experimental work with rotating mirrors and other



Drawings by] [*W H Steavenson*

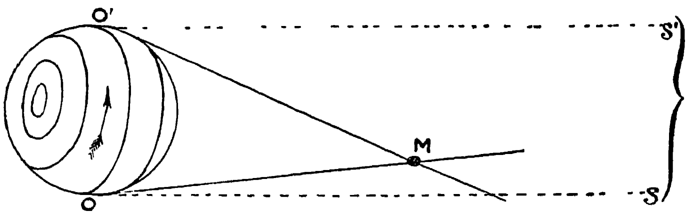
EXPLANATION OF THE "BLACK DROP"

When Venus is projected wholly within the Sun's limb the edge of her disc is encroached upon to an appreciable extent by the effects of irradiation and diffraction, so that she appears somewhat smaller than she really is When, however, her true limb is in contact with that of the Sun the causes of this encroachment are no longer operative at that point, and we see a portion of her disc that was not seen before This naturally appears in the form of an excrescence, and is known as the "black drop"

devices the velocity of light has been found to be 186,325 miles per second, and from the delay in the times of the eclipses of Jupiter's moons the diameter of the Earth's orbit can be deduced

The knowledge of the velocity of light can also be applied to the problem of the Sun's distance by means of the phenomenon known as the "aberration of light" As a result of the fact that the propagation of light is not instantaneous, a star is slightly displaced from its true position in the sky Each star appears to revolve once a year in a small elliptic path about its average position One situated in the plane of the Earth's orbit merely oscillates on either side of a mean position and the breadth of the ellipse grows until it becomes a circle at the pole of the ecliptic

The fact that the velocity of the Earth in its orbital motion round the Sun forms a sensible fraction of the velocity of light is the cause of this aberration, which may be understood by a simple illustration When an object is let fall down the centre of a vertically disposed tube, it will go straight to the bottom without touching the side, if the tube is at rest If a forward movement is given to the tube, however, the object would only pass down its centre without touching the side providing the tube were inclined at an angle So it is with light coming from a star and passing down the tube of a telescope on a moving Earth The telescope has to be pointed slightly away from the true direction of the star



PARALLAX OF A MINOR PLANET
The distance of a minor planet (M) from the Earth is found by measuring its position with reference to the background of fixed stars (S and S') To observers at O and O' (or to a single observer carried by the Earth's rotation from O to O' the planet and the stars behind it have a different configuration, and from this apparent displacement and the known relative distances of the planet and the Earth from the Sun, the solar parallax can be found with more accuracy than by the Transit of Venus method

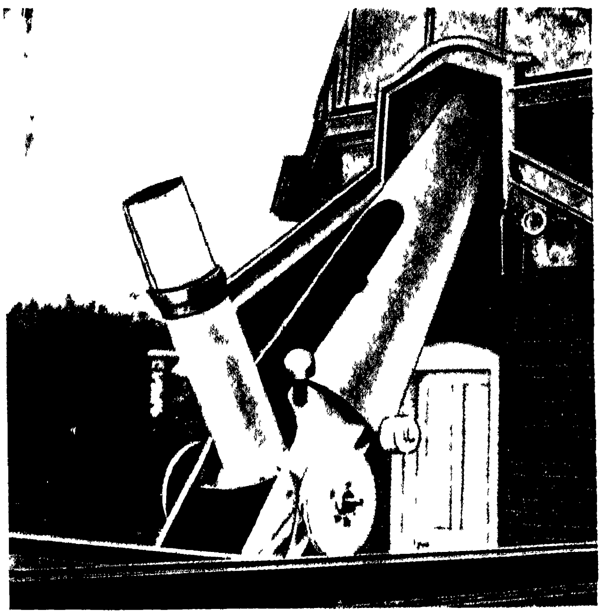
When the small ellipses are measured, the angle is found to be somewhat less than twenty and a half seconds of arc By a simple calculation it is found that the velocity of light must be very nearly 10,000 times the speed of the Earth in its orbit, which thus comes out at about eighteen and a half miles per second The circumference of the orbit in miles is therefore eighteen and a half times the number of seconds in a year and the semi-diameter, or distance of the Sun, is easily deduced

Another indirect method of ascertaining the distance of the Sun is based on investigations of the velocities of the stars in the line of sight as revealed by the displacements of the lines in their spectra At one season of the year, the Earth in its orbital movement is approaching a star, while six months later it is receding from it Determinations of these motions of approach and recession with reference to a number of stars can be made and an accurate knowledge of the Earth's orbital speed derived from which the circumference and radius of the orbit are calculated This method is susceptible of very great accuracy and increasing precision in the solar parallax value, as instrumental means improve and greater numbers of stars are utilised

The same method has recently been applied to the changing velocity of the Earth itself As the orbit is eccentric, the Earth is sometimes approaching the Sun (July to December) and sometimes receding from the Sun (December to July) These motions of approach and recession are shown in the displacements of lines in the Solar Spectrum, and when they are measured and discussed the scale of the orbit can be calculated A similar method can also be applied to the radial velocities of the other planets

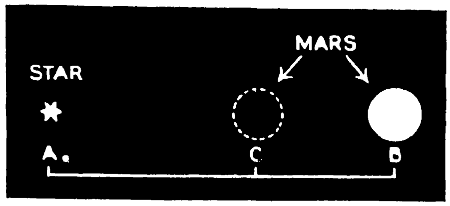
The space which has been occupied in the foregoing discussion is justified by the very great importance of the problem of the Sun's distance It is the fundamental datum of Astronomy—the unit of space, any error in the estimation of which is multiplied and repeated in many different ways, both in the dimensions of the Solar System and in those of the universe in general The number which represents it is involved in almost every calculation of distances or masses, of sizes and densities either of planets or their satellites, or of the stars Its determination has been referred to as one of the noblest problems of the science, and great expenditure of human effort and wealth has been made in attempts at its solution

It is also among the most difficult tasks of the astronomer, involving as it does, in the direct methods, an attempt to measure an angle



SHEEPSHANKS EQUATORIAL, CAMBRIDGE OBSERVATORY
This telescope was used very successfully in the determination of the solar parallax by photographs of Eros in 1899 and 1900 It is a modification of the "coudé," or elbowed, type of equatorial The tube itself acts as the polar axis, so that the eye end (inside the building) remains stationary, but for rotation This makes observation very comfortable and convenient

about equal to that subtended by a halfpenny 2,000 feet from the eye, within about a thousandth part of its value The scale of the entire Solar System follows very simply from the relation between periods of revolution and distances already mentioned, and in the case of the planet Neptune, we have the largest distance from the Sun which is thus directly derived—about thirty times the distance of the Earth from the Sun, an enormous gap over which the sunlight takes over four hours to pass, although the speed of light is such as would encircle the Earth's equator more than seven times in a second !



[W H Steavenson

"PARALLACTIC" SHIFT OF MARS

When Mars is close to the Earth his apparent position among the stars varies with the position of the observer on the Earth, or with the motion given to a single observer in a few hours by the Earth's rotation The amount of shift (BC) in relation to a comparison star (A) gives a measure of the distance of the planet, after taking into account the distance moved by the observer

Great as this is, it pales into insignificance beside the distances of the stars When we come to the investigation of stellar remoteness no base line on the Earth is long enough, and we must use something much greater The Earth makes this base line for us in its orbit round the Sun, and, large as it is, it is all too small for the purpose

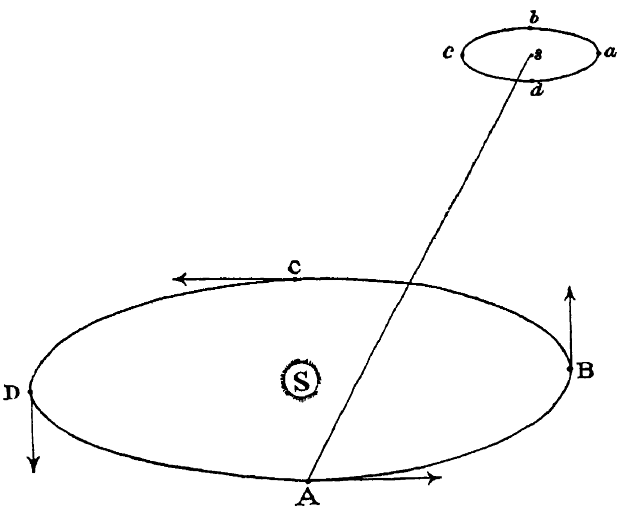
If the position of the star chosen for the investigation is determined in the sky as accurately as possible, say in the month of March, and then again after an interval of six months in September, the other end of the base line of 185,800,000 miles will have been attained, and if a difference is found in the positions as observed, the star's distance can be found The parallax of a star is the angle made at the star by the radius of the Earth's orbit, or, to put it in another way, is the angle which would be occupied by a line 92,900,000 miles long at the Sun when seen from the star in question

The slight movement in the position of the star is found by measures between it and fainter and probably more distant stars, though this is an assumption which is not always true, as is proved by the occasional *negative* results for parallax, which indicate either that the chosen star is really farther away than the average of the fainter comparison stars used, or that the parallax is too small to be within the limits of error in the measurements

The determination of stellar parallax is comparatively simple but for the extreme minuteness of the quantities concerned An idea of their smallness may be gained from the statement that if two railway lines starting in London, met in Newcastle instead of keeping parallel all the way, the angle between them would be of the order of magnitude to be measured in finding the distance of the nearest stars

There is no star known for which the parallax is as great as one second of arc , a second of arc is less than one millionth of the distance round the circumference of a circle, and is the angle subtended by a tennis ball about eight miles away or by a six-foot man at 250 miles distance

Yet 92,900,000 miles looks smaller than this when seen from the distance of the very nearest of all the stars of which the parallax has been measured This is "Proxima Centauri," a faint star situated near to and physically connected with the bright double star α Centauri, one of the brightest stars in the southern sky, which is itself the next

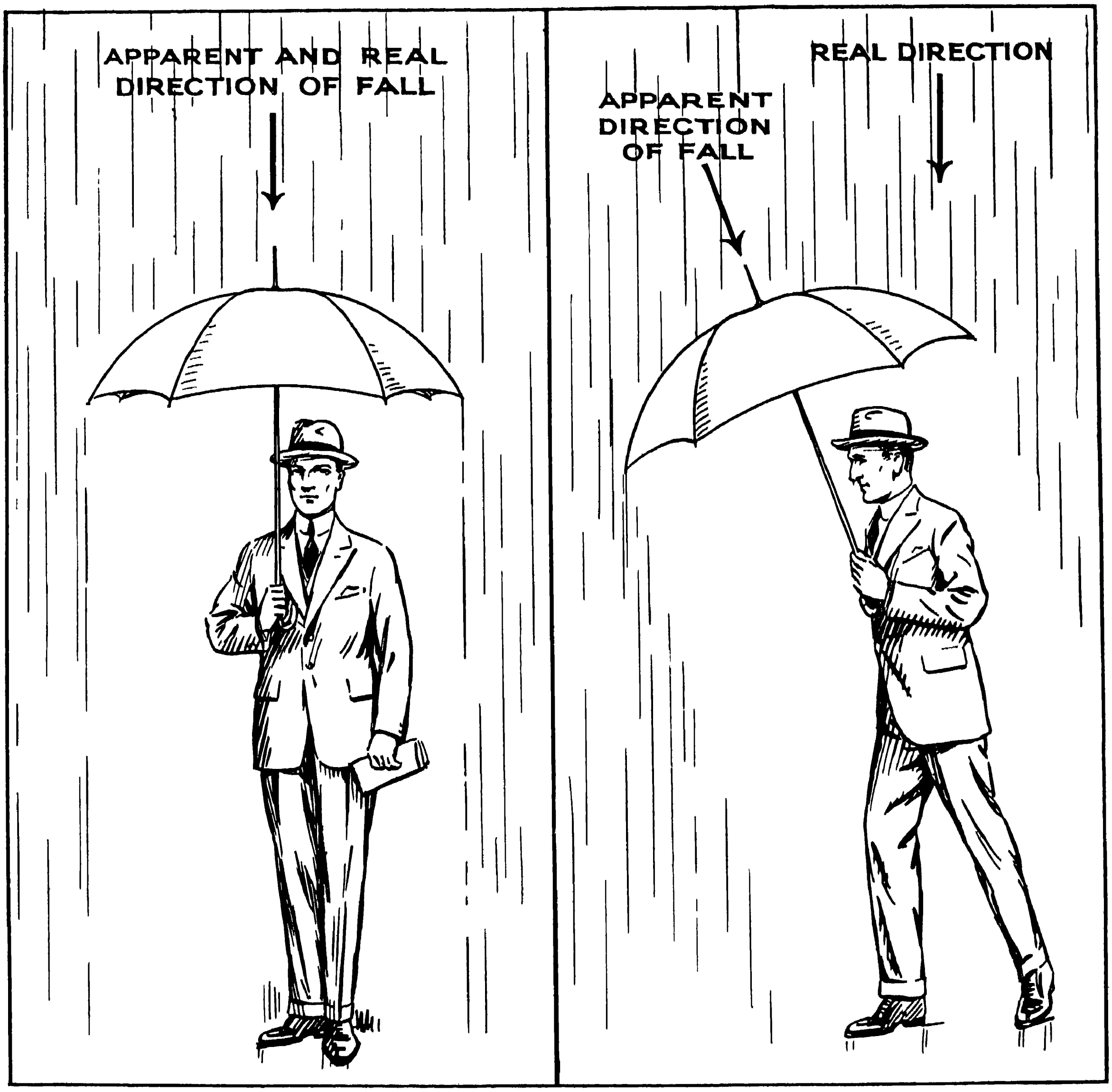


ABERRATION OF LIGHT

The diagram illustrates the effect on a star's apparent position of the Earth's motion in its orbit A star *s* would appear in the direction A*s* if the Earth were at rest at A, actually it is seen at *a*, slightly ahead of its place, and in a year describes a small orbit on the sky, *abcd* corresponding to the points ABCD in the perspective view of the Earth's orbit

nearest known The parallax of " Proxima " is seventy-nine hundredths of a second, corresponding to about twenty-four billion miles distance, or a light journey of four and one-tenth years

The processes used in measuring these very small angles are similar to what has already been described for the minor planets, although the stellar parallaxes are very much smaller The older methods used were those depending upon astronomical instruments which measure the places of the stars with great accuracy—the meridian circle, the micrometer and also the heliometer So minute are the quantities to be measured that the instruments themselves, although made with graduated scales and screws of almost superhuman precision of workmanship, have to be tested for their errors which are then used as corrections to the results Not only the instruments have to be analysed in



From a Drawing by] [*W H Steavenson*

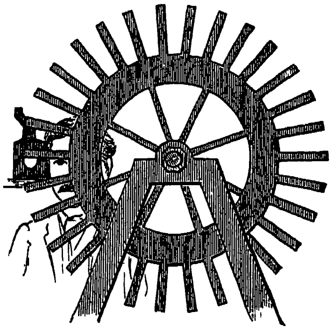
EXPLANATION OF " ABERRATION "

It is a familiar fact that the apparent direction of the drops in a shower of rain is altered by the motion of a person walking or running through it The angle at which the drops appear to fall depends upon the ratio between the velocity of their descent and the motion of the observer In the case of Light the speed of the Earth in its orbit is small compared with the enormous velocity of 186,000 miles per second, so that the change of apparent direction is small But the principle is the same, and our telescopes (like the man's umbrella) must be directed slightly ahead of the place where the star would appear if we were stationary

this way, however, but also the personal errors of the observers which vary from one individual to another

The conditions under which the observations are made have to be kept the same as far as possible Even after all these precautions there are outstanding discrepancies in the best results, which are often of the same order of size as the quantities to be measured While these visual methods have given very valuable service, photography is to-day much the better for stellar parallax work

If two photographs of the same region are taken six months apart, the shift of the " parallax star " can be measured with reference to a number of comparison stars, by means of a microscope Minute precautions must be taken with this method also, as the quantities to be measured on the photographic plate are generally only a few hundred thousandths of an inch

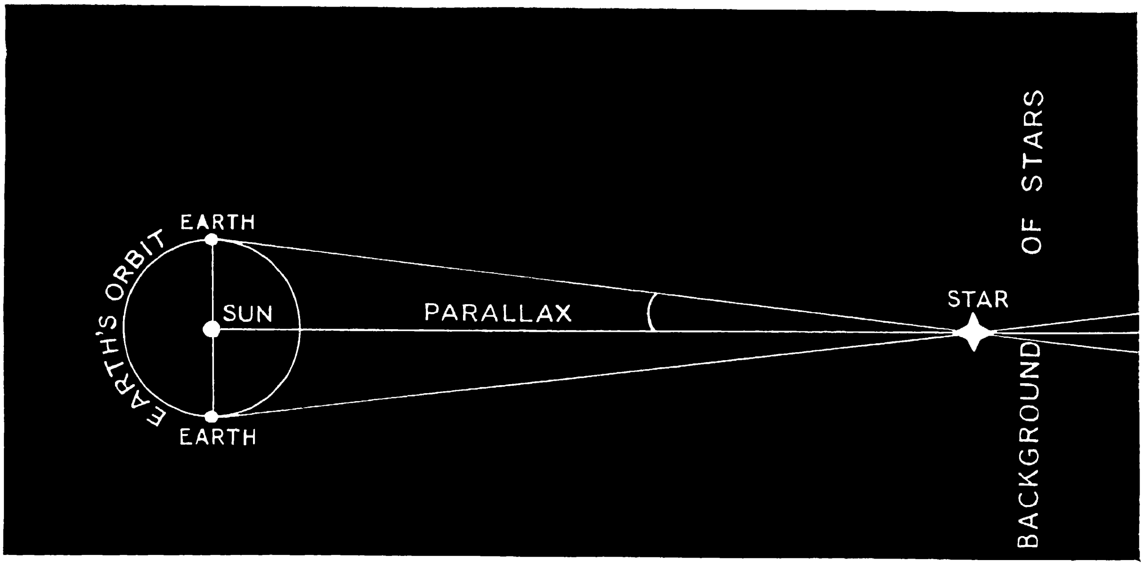


MEASURING THE SPEED OF LIGHT

A toothed wheel, revolving rapidly in front of a lamp, was used by Fizeau to measure the velocity of Light A distant mirror sent back the rays that passed between the teeth, and by noting the velocity of rotation whereby the returning ray could just be caught on the next (or some later) tooth, the speed at which the light had travelled could easily be deduced

To form an idea of what is now being done with large photographic telescopes in stellar parallax work, the reader may imagine two plumb-lines five feet apart They are sensibly parallel but of course actually would meet, if produced, at the centre of the Earth The angle between them is only one-twentieth of a second, yet angles of this size are now being measured in photographic work with an accuracy of nearly one-fifth of their size, *i e*, one-hundredth of a second of arc ! About fifty years ago the then Astronomer Royal (Sir George Airy) referred to an angle ten times this size as the " smallest thing in the world " , considerable progress has evidently been made !

A great deal of care is required in taking the photographs and in measuring them The small images of the stars have to be as accurately round as possible so that the centres can be estimated to within a fiftieth or a hundredth of their diameters To make for the necessary accuracy, the telescope must be guided as perfectly as possible in following the stars in their motion across the sky due to the Earth's rotation The photographic image of the parallax star should not be larger than the comparison stars, and as it is usually brighter, this is effected by the use of a rotating shutter partly covering the image



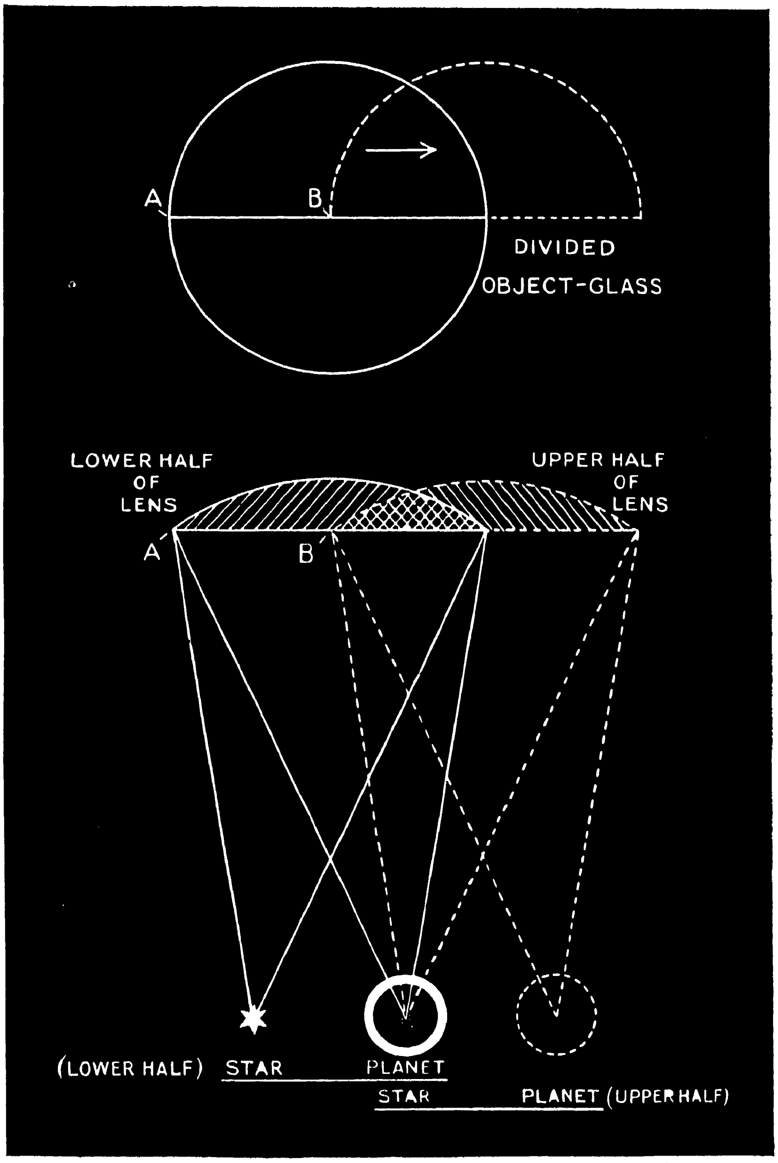
PARALLAX OF A STAR

The 185,800,000 miles width of the Earth's orbit makes a base line from each side of which a star is observed at an interval of six months Half the angular displacement with reference to the fainter and remoter background stars is called the " annual relative parallax "

of the star and thus lessening the quantity of light received from it on the photographic plate, or by local chemical treatment of the plate or other means

The best modern parallax determinations made by the most skilful observers employing powerful telescopes (ranging from 20 to 100 inches diameter) are yielding reliable parallaxes for stars up to 200 light-years distance, corresponding to a parallax of sixteen-thousandths of a second of arc Greater distances than this are not at present accurately measurable directly, owing to the unavoidable errors of observation, which are then comparable in size with the parallaxes themselves In short, the base line of the Earth's orbit is too small for the direct measurement of greater distances with present instruments and methods Several observatories are devoting themselves largely to this line of work, however, and as a result of their labours there are now over 1,200 reliable parallaxes measured in this way, which number is increasing at the rate of about 200 per annum

It may be well at this stage to explain what the astronomer means when he estimates the accuracy of a result by what he terms its "probable error" It can be illustrated in a simple way Let the reader suppose that he is given the task of measuring the length of a field with an ordinary foot-rule, and asked to get as accurate a result as possible With this in view he will realise that a number of separate measurements of the field laboriously undertaken and then averaged will give a better result than one measurement however carefully performed If he makes, say, twenty sets of measurements it will be found that no two of them will agree but that some are several inches larger or smaller than the average of the twenty



Drawing by [*W H Steavenson*

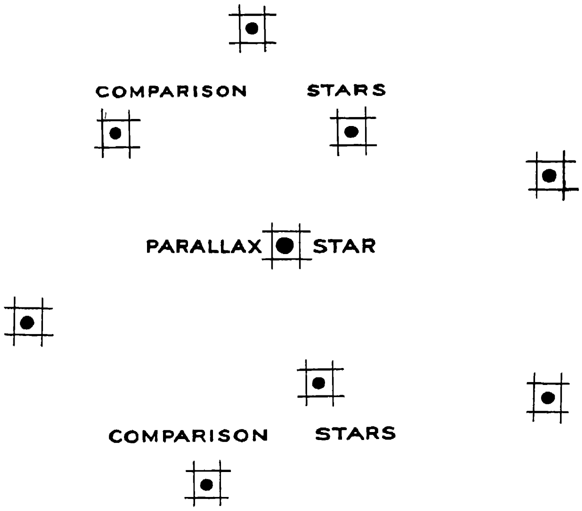
PRINCIPLE OF THE HELIOMETER

The heliometer was devised originally for measuring the diameter of the Sun, whence its name It has also been used for measuring angles which are too large to be readily compassed by the ordinary eye piece micrometer The object glass is divided into two portions, capable of sliding on one another Each forms its own set of images, like a complete lens, and these images can be displaced with regard to one another by sliding the two halves of the object glass The lower half of the diagram shows how, in measuring the distance between two objects, the two halves of the lens have to be relatively shifted through the same distance (AB) as that which separates the images of the objects The distance AB is read off on a scale when the two pairs of images are separated to the extent shown

This average would be the most probable value for the length of the field, and from the deviations of all the separate twenty measurements a surveyor could calculate a quantity which he would call the "probable error" of the result. This quantity is to some extent a measure of the accuracy of the work. Manifestly a probable error based on a hundred measurements would be smaller than one got from twenty sets and one from twenty carefully-made measurements would be smaller than that derived from twenty not so precisely undertaken.

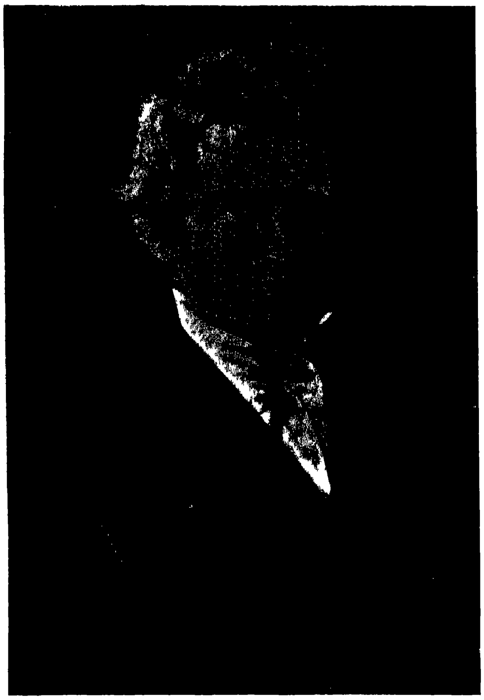
This probable error, however, is not necessarily the true measure of the correctness of the result. It is a measure of the *accidental* errors, but not of any error which may be constantly present, such as would be involved in the use of a foot-rule which was slightly too long or too short, or in some systematically defective manner of applying the foot-rule.

In the same way the astronomer's "probable errors" are not necessarily the true ones – there may be (or rather, there certainly are) "systematic errors" also. Both kinds of error are being lessened as time passes, by the use of better instruments and superior methods of work, but nevertheless are yet present to such an extent as to render of little value very small parallaxes of the order of one-hundredth of a second or so, when obtained by the usual direct methods of measurement.



STELLAR PARALLAX BY PHOTOGRAPHY

Two photographs are taken, at an interval of several months, and in each case the position of the image of the near star is measured with regard to a number of fainter surrounding stars, which are presumed to be more distant. At Greenwich the method has been adopted of cutting fine lines with a diamond on a separate plate of glass near the position of each star. The glass plate is then used as a standard of reference, being placed in contact with each of the two photographs successively, the measures in each case being made relative to the engraved lines.



From Bryant's "History of Astronomy" [*By permission of Messrs Methuen & Co., Ltd*

BESSEL (1784—1846)

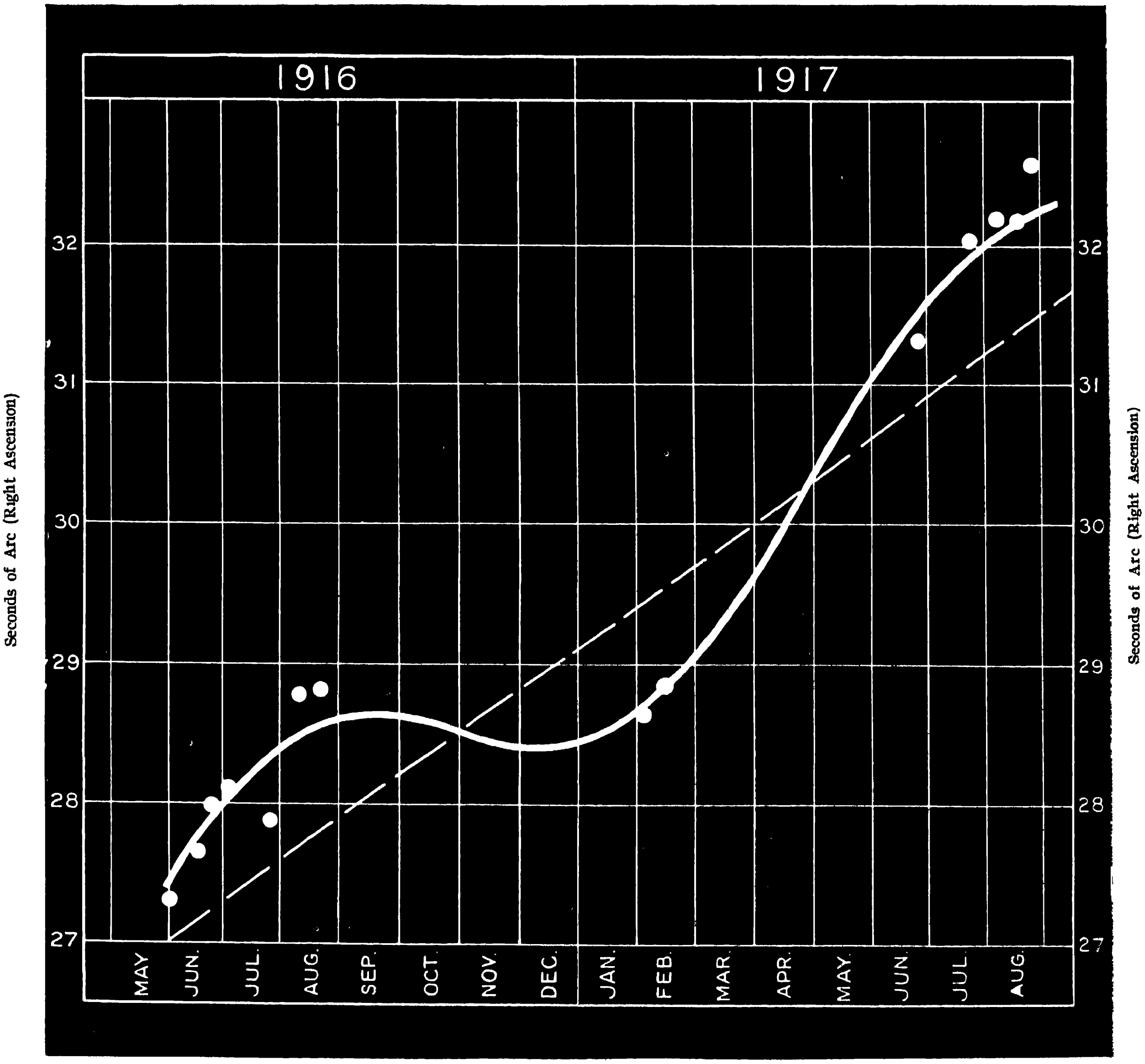
To Bessel we owe the first reliable measure of a star's distance. His measurement of the parallax of 61 Cygni with the Konigsburg heliometer in 1838 marks the beginning of our accurate knowledge of the scale of the sidereal universe.

Our twenty-five nearest neighbours are contained within a sphere with the Sun at the centre, across which light would take thirty-two and a half years to pass. It is probable that there are few, if any, others in this great volume. If we enlarge the sphere to sixty-five light-years diameter there are over 100 known, although there are very probably nearly another 100 more in this volume for which the distances are not yet determined, particularly in the southern skies, which are not yet so well explored for parallax as those regions dealt with by the more numerous northern observatories.

Many of these stars are binaries, two suns revolving in great orbits about a common centre of gravity. It is of interest to note that the number of binaries in the volume of space referred to, bears about the same ratio to the number which are single stars, as that found for the stars generally. In the twenty-five stars nearest to

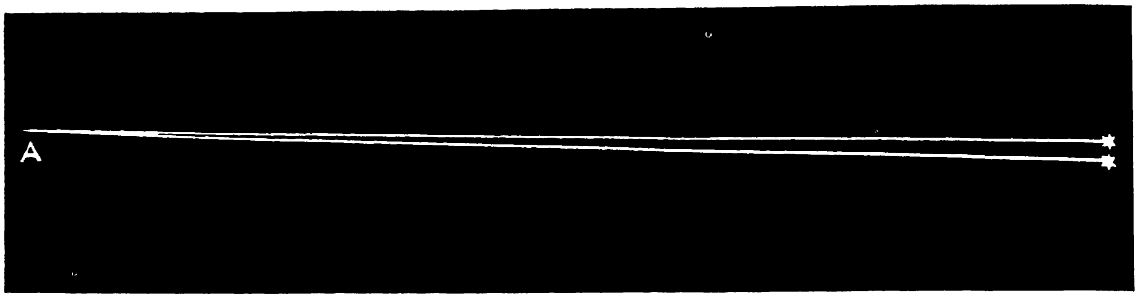
the Sun there is a great diversity of real brightness The most luminous star among them is Sirius, which gives a light output about twenty-eight times that of the Sun, and the faintest is Proxima Centauri, which shines with only about one-seventeen-thousandth of the Sun's light In a later section of this work will be found a description of the division of the stars by their luminosities or total light output, into two classes, the "giants" and "dwarfs" There are no stars which can be properly described as giants (although Sirius almost deserves the name) until a greater distance than the sphere containing the twenty-five nearest stars has been passed, the Sun itself being a dwarf star

So far we have only dealt with the effect of the observer's motion, when carried round the Sun in the Earth's orbit, upon the apparent position of a star For over 200 years, since Halley detected



PARALLACTIC SHIFT OF "PROXIMA CENTAURI"

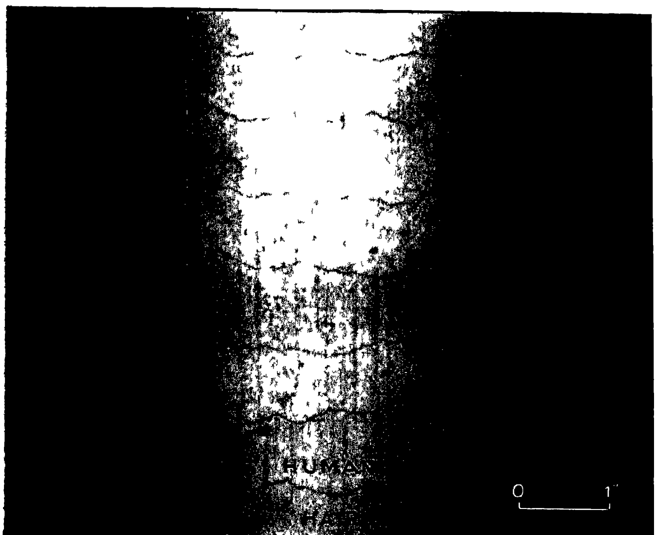
This diagram shows the effect of the swing of the Earth in its orbit round the Sun on the apparent position on the sky of the nearest star, Proxima Centauri The angular distance from a neighbouring and very remote star is measured at intervals and plotted down The straight dotted line shows these distances without the effect of the Earth's motion in its orbit, the waving line shows this effect, which repeats itself with a period of twelve months



AN ANGLE OF ONE DEGREE
To an observer at A the two stars on the right appear separated by just one degree, or one three hundred-and sixtieth part of a circle The inclination between the two directions appears small enough, but astronomers are accustomed to measure accurately angles as small as a hundredth of a second of arc This minute angle is only one three hundred-and-sixty-thousandth of that shown in our illustration !

in 1718 the changes in position in the sky of Arcturus, Procyon and Sirius since ancient times, it has been known that the stars also are moving When accurately determined positions of the stars, made at considerable intervals of time, are compared with each other, it is found that some have changed their position in the sky by appreciable amounts This change in position is termed the star's "proper motion "

Although stellar proper motions are very minute, it is clear that after a sufficient lapse of time the familiar configurations in the heavens will be much disturbed except where the stars concerned are moving together In the Plough, for example, the five intermediate stars of the seven are moving in approximately parallel lines, although the star at each end is moving in another direction Thus there was no Plough for the men of the Stone Age, and there will not be one for our descendants thousands of years hence Associated with the five stars mentioned are a number of others close to them in apparent position and also some scattered widely over the sky, of which the most notable is Sirius These stars form a great cluster, the members of which are travelling together through space although separated by enormous distances



Drawing by] [*W H Steavenson*
THE MINUTENESS OF PARALLAX MEASURES
This illustration gives some idea of the minuteness of the quantities actually measured in determining stellar parallaxes by the photographic method A second of arc on one of the Greenwich parallax plates is about one third of the diameter of a single human hair, and yet displacements of stars are measured correct to one hundredth of this minute angle

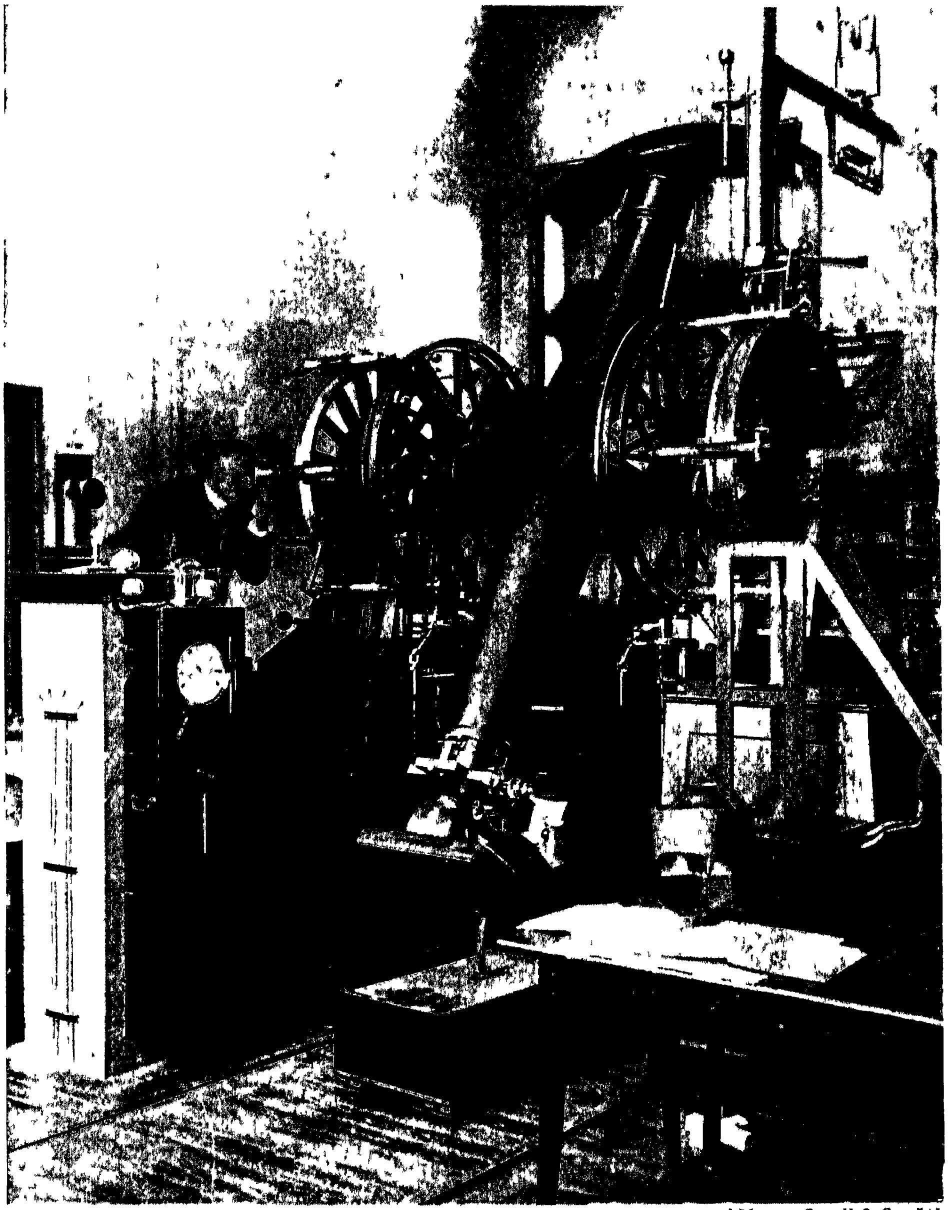
By a similar community of proper motion astronomers have been able to recognise a number of groups, the Taurus cluster, the Pleiades, the stars in Orion, those in the Beehive (Praesepe), and a numerous scattered group of stars of great luminosity in the constellations Scorpius and Centaurus The members of these clusters are physically related and the methods of estimating their distances will be referred to later

When the proper motions of a number of stars distributed over the heavens were studied, it was noticed that while there was a considerable amount of random movement in all directions, yet there was a strong tendency for the motions to be directed towards a particular point on one side of the sky and away from a point directly opposite on the other side The astronomer who was

first to explain this as due to a motion of translation of the Solar System in space, was Sir William Herschel in 1783 His conclusion was that the point of the sky from which the stars appear to be separating is the one towards which we are moving, and that the opposite point to which the stars generally appear to converge was the direction from which we are receding in space

The apparent motions of the stars are therefore made up of their own individual movements, combined with that of the Sun reversed The earlier investigators, who corroborated Herschel's results as regards the direction of movement, could not determine the speed of translation In order to do this the distances of the stars would require to be known so that the angular motions could be turned into linear movements

In considering the proper motions of the stars it must be remembered that our observations do not give the true direction or amount of the entire motion, but merely that part of it which appears as a change in position of the star in a plane at right angles to the line joining it and the observer Of the component of motion in the " line of sight " nothing was known until the application of the spectroscope to the problem By the displacements in the lines of the spectra of the stars, we are now able



From " Astronomy for All "] [*By permission of Messrs Cassell & Co, Ltd*

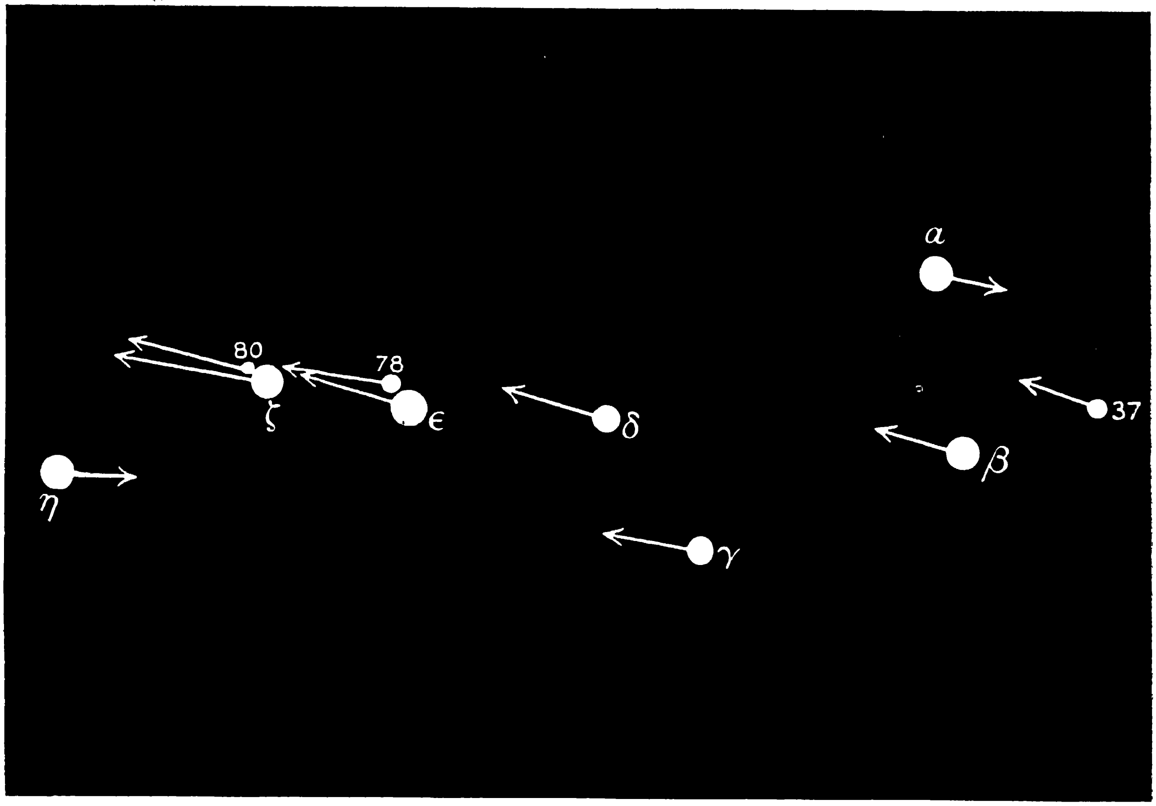
A MERIDIAN CIRCLE

This is the type of instrument whereby the apparent positions of stars in the sky are determined with great precision For this purpose it is provided with circles divided very accurately on silver or gold and the divisions are read by means of microscopes Continuously repeated observations of the same stars year after year have provided data for calculating the proper motions of the brighter stars, but those of the fainter ones are now generally deduced from the measurement of photographs

to measure accurately the speed in miles per second with which a star appears to be approaching to or receding from us As in the case of angular proper motions, the observed speed in the line of sight, or radial velocity, is that of the star and the component of solar motion in its direction

From observations of radial velocities of stars in all parts of the sky, it has now been found that the Solar System is moving with reference to the system of the surrounding stars, with a speed of about 12 1 miles per second towards a point on the borders of the constellations Lyra and Hercules not far from the bright star Vega This velocity will carry us about 382 million miles in a year, so that the stars near us at the present time are generally a different set from those previously occupying the solar neighbourhood, and in the future others will take their place

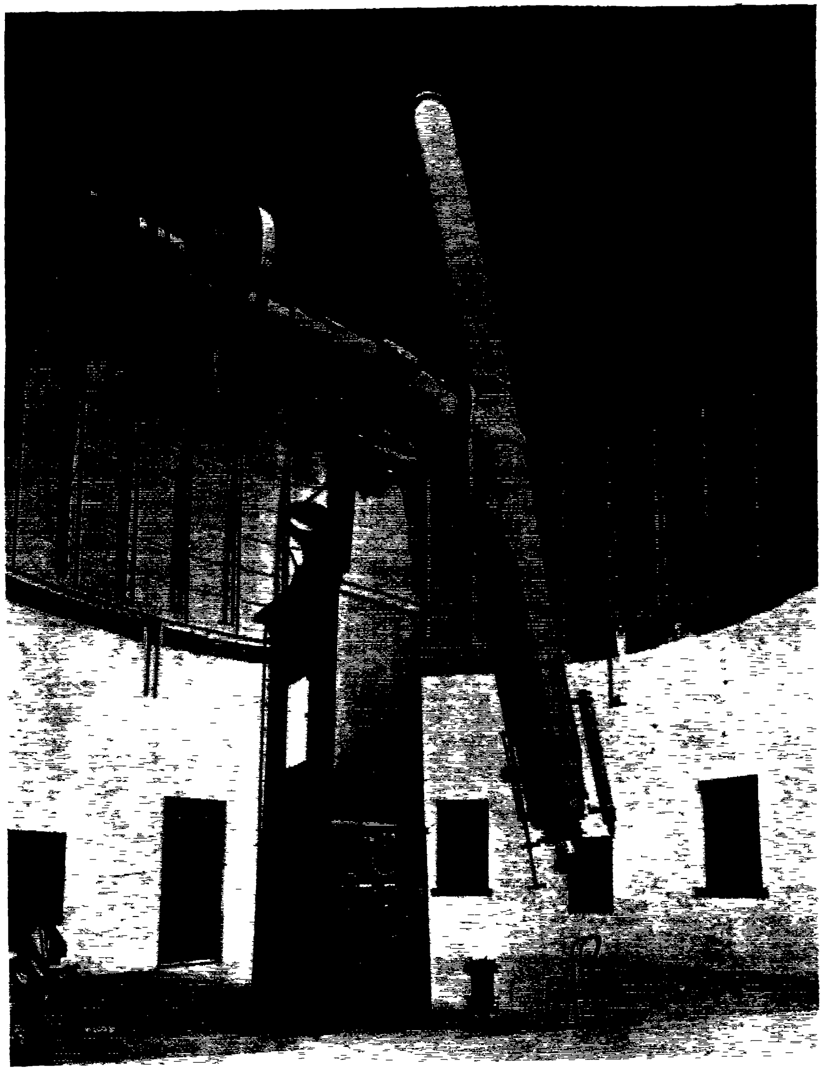
This motion provides us in the course of time with a much greater base line than the diameter of the



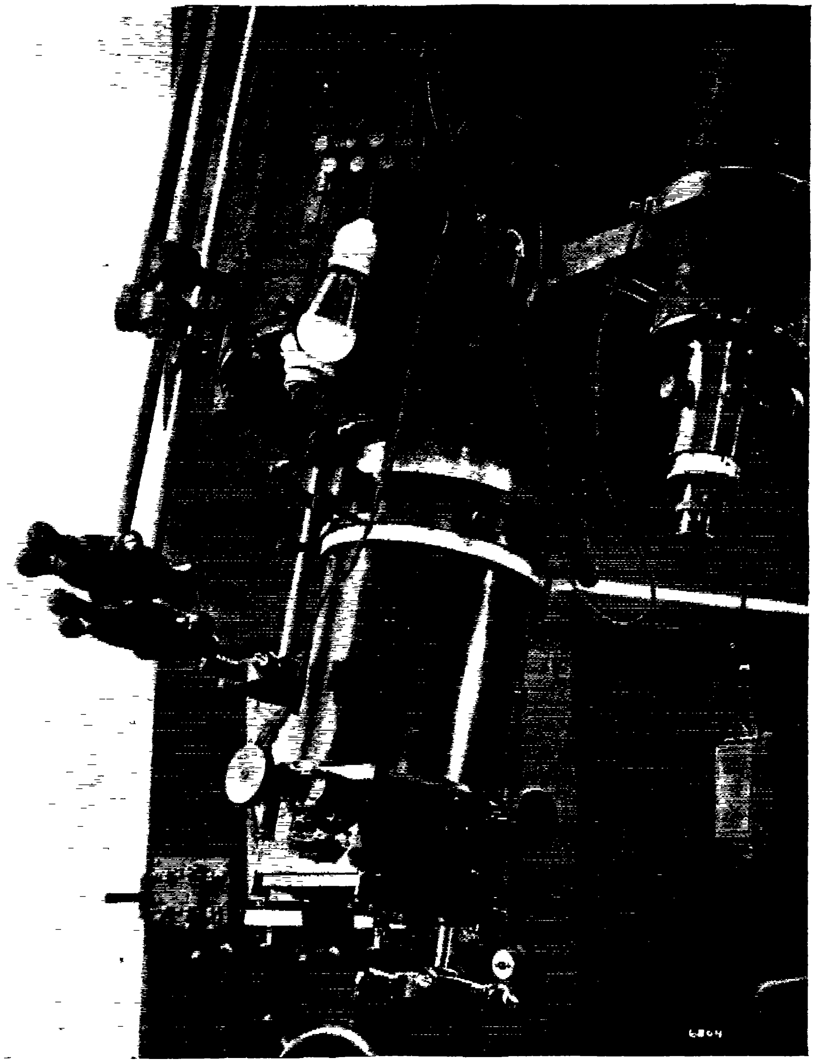
MOTIONS OF THE STARS IN THE PLOUGH
This diagram shows on an exaggerated scale the motions in the sky of the Plough and neighbouring stars All but Alpha and Eta are moving together through space, and are situated at a distance from the Earth which Light, moving at 186,300 miles per second would take about eighty years to traverse !

Earth's orbit, for the measurement of stellar distances A star which would shift its position in the sky by only one-hundredth of a second of arc while the Earth in its orbit moved from one side to the other of the Sun, would show a shift of nearly two seconds, after the lapse of 100 years, from the motion of the Sun through space, and two seconds of arc is an angle which although very small, is much easier to measure than one-hundredth of a second Similarly, the small proper motions of the stars which are too minute to be seen in a year's time become noticeable in a century, and the careful observations of several generations of astronomers have provided us with the changes in position from which are derived the motions of the stars across our line of vision which are termed their proper motions

This new base line enables us to determine the average distances of groups of stars on the assumption that the different stars are moving in random directions and that therefore their individual motions



THE SPROUL TELESCOPE



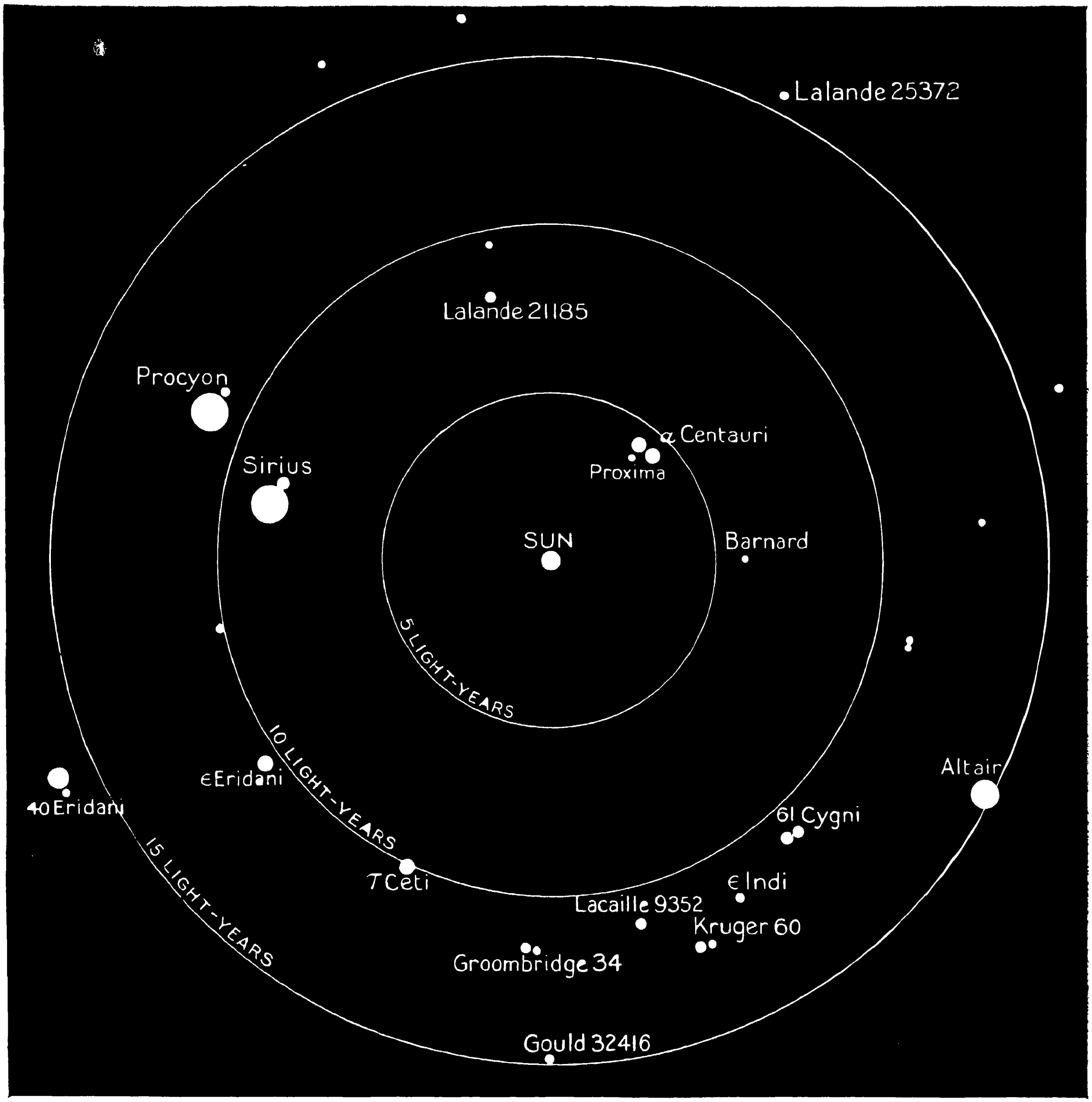
PLATEHOLDER OF SPROUL TELESCOPE

From ['Popular Astronomy

The above views are of the Sproul refracting telescope of twenty-four inches aperture and thirty-six feet focal length which is chiefly used for taking photographs of stars at intervals of several months for the purpose of determining their distances It is the gift of a wealthy American to Swarthmore College, Pennsylvania

cancel each other in taking the average From studies of this kind, we have been able to get reliable information regarding the distances of the great clusters and groups of stars and as a consequence to penetrate farther into space than by the direct measurement of individual parallaxes

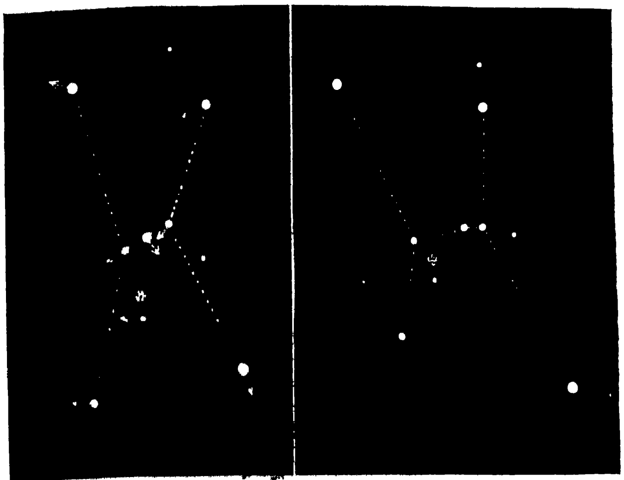
For example, we may find the average parallax of the stars of a particular grade of brightness by



THE TWENTY FIVE NEAREST STARS.
Our nearest twenty five stellar neighbours (eight of which are double) are here shown at their relative distances Their total brightnesses vary from twenty-eight times (Sirius) to about a seventeen-thousandth (Proxima) of the Sun The relative sizes of the stars are approximately as shown but are exaggerated enormously in comparison with their distances apart

the use of this base line. As is described in another chapter, the stars are graded in stellar magnitudes, those visible to the naked eye being included in the first six magnitudes or so

Taking each class and dealing with that part of their proper motions which is a reflex of the translation of the Solar System through space, averages as follow have been determined It should be borne in mind that there is a great diversity of brightness in the stars, and that consequently those which are



From "Astronomy for All"] [By permission of Messrs Cassell & Co, Ltd

ORION TO-DAY AND AGES HENCE

The proper motions of its individual stars will, in the course of many thousands of years, completely distort the whole constellation and render it utterly unlike the familiar form we know to-day

classed together in a particular grade of apparent brightness are really at extremely varying distances The figures given are therefore only rough averages Meanwhile it will be as well to note that (as will be described in the chapter on Giant and Dwarf Suns) the redder stars have a much greater diversity of brightness and distance for a given apparent magnitude than the whiter ones

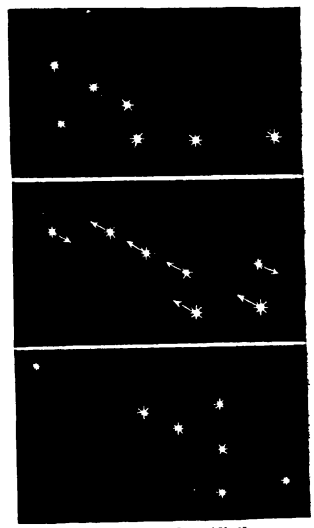
First magnitude		80 light-years	
Second	,,	100	,,
Third	,,	135	,,
Fourth	,,	170	,,
Fifth	,,	215	,,
Sixth	,,	280	,,

There is another method by which the measured proper motions and radial velocities are utilised to give average distances of groups of stars Perhaps a simple illustration will help us in making clear the means by which this is done The reader may imagine himself at sea and that all round are a number of very distant boats moving at random in all directions With a telescope the motions can be studied and tabulated so that we could say, for example, that the boats were moving on an average perhaps ten degrees of arc per hour across the field of view This by itself would not tell us anything about the distance of the boats

If, however, we knew that the actual rate of movement across our field of view were on the average five miles per hour, some moving faster and some slower, then the problem would be to find how far away an object must be so that a base line of five miles must look like ten degrees The answer would be that the boats must be, on the average, about twenty-eight miles from us Some might be much closer and others much farther away, but if their average movement across the field of our telescope were ten degrees per hour and we were able to find that their average actual movement was five miles in an hour, we should be able to ascertain their average distance as given above

In the case of the stars the problem is more complicated than in the simple illustration, as the observer is in motion due to the translation of the Solar System The value of the Sun's own motion through space must therefore be eliminated from the observed radial velocities of the stars and that part only of the proper motions used which is not affected by the journey of the Sun through space

The measurement of the distances of clusters of stars such as those mentioned in an earlier paragraph is made by a variation of this method In the case of the Taurus Moving Cluster, which consists of a number of stars of about the fourth magnitude and fainter situated mainly in the constellation Taurus with the Hyades cluster nearly at its centre, common proper motions have been known for some time When these motions are shown graphically a striking feature presents itself They are all apparently converging to a point in the sky about five degrees east of



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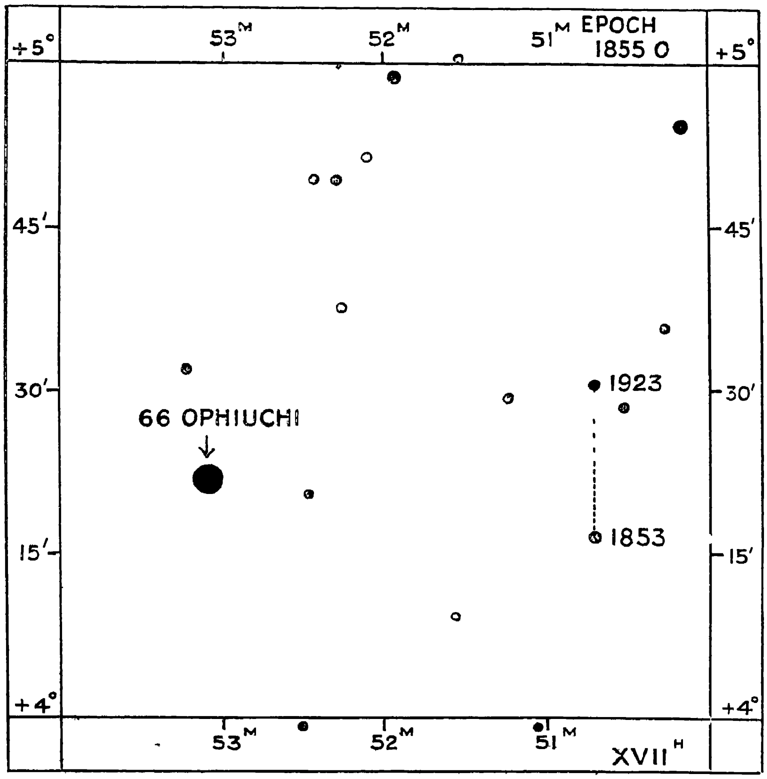
CHANGES IN THE PLOUGH IN 200,000 YEARS

The middle picture shows the Plough as it appears to us to-day, the arrows indicating the directions in which the individual stars are moving The motions are too slight to make any obvious change in the shape of the group in a short time but the upper and lower pictures show the effect of the movement 100,000 years hence and 100,000 years ago respectively



Drawing by] [*W H Steavenson*

A RUNAWAY STAR

An insignificant star in Ophiuchus, between the ninth and tenth magnitude, was shown by Barnard in 1916 to have the largest proper motion yet known This motion amounts to 10 3 seconds of arc per year, enough to displace the star a Moon's breadth in about 190 years The chart above will enable any observer to find the star (with a small telescope) after identifying the star 66 Ophiuchi on a star chart The motion in seventy years is indicated by a dotted line

the bright red star Betelgeuse

An exactly similar converging motion is observed in the case of the apparent paths of a flock of birds or squadron of aeroplanes which are flying across our line of sight and at the same time receding from us Now the receding radial velocities have been spectroscopically measured for a number of the stars concerned, and consequently we can calculate the true paths of the stars of the cluster in space assuming that they are really parallel and that their convergence is only apparent and due to their recession from us We can then compute the distance of the cluster as about 130 light-years and also its dimensions assuming the shape to be roughly spherical The diameter would appear to be about fifty light-years or nearly twelve times the distance separating the Sun and the nearest star Independent measures of parallax of some of the stars by various methods corroborate these values By this and other methods referred to later, the distances for well-known clusters and groups of stars have been found as below —

Cluster or Group	*Approximate Distance, Light-Years*
Stars in the Plough	80
Stars in Taurus Group (including Hyades)	130
Stars in constellation Coma Berenices	290
Moving Group in Perseus	350
The Pleiades	350
The Beehive (Praesepe)	400
Stars in constellation Orion	600

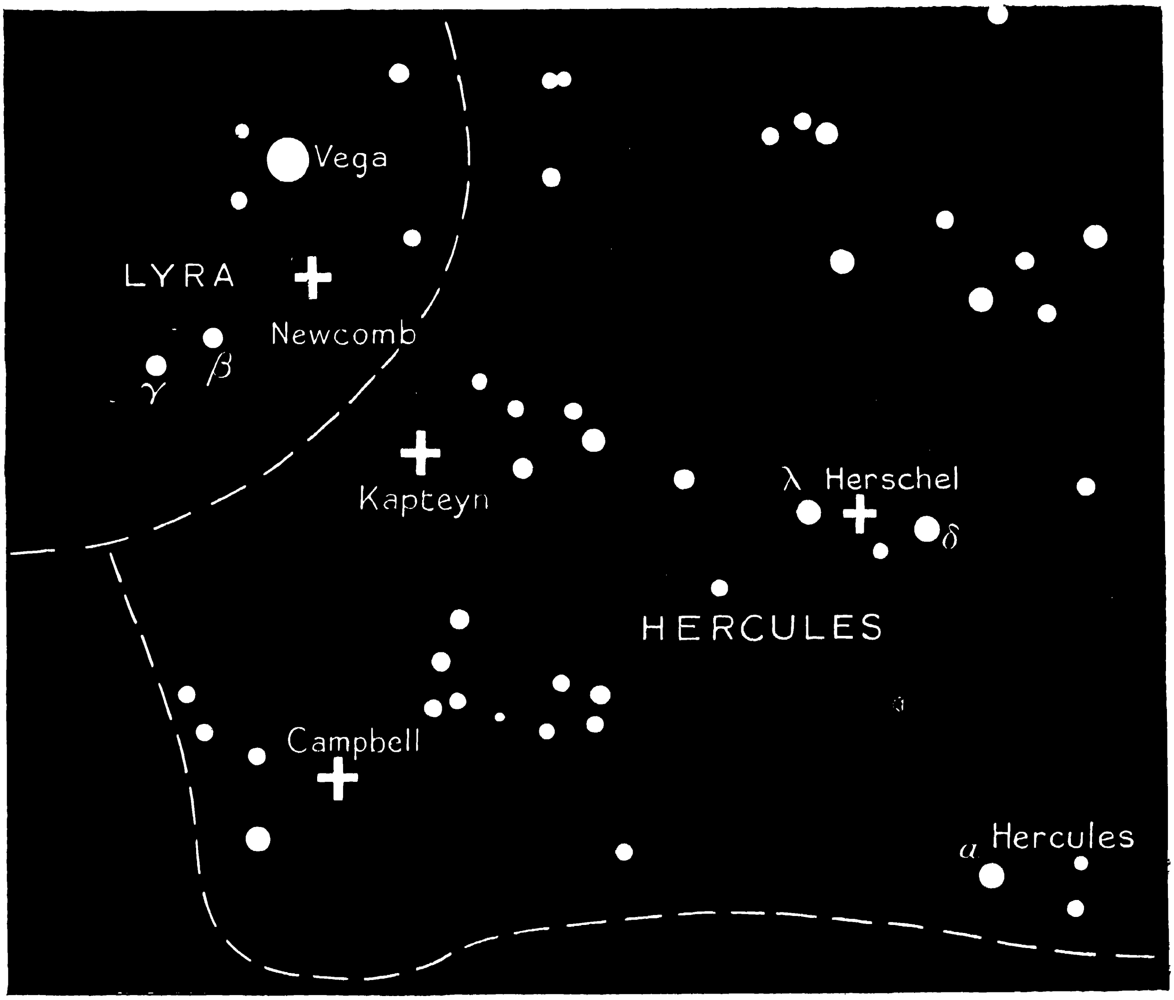
As in the case of the problem of measuring the Sun's distance, there are some indirect ways of getting at the distances of the stars in addition to those based on the apparent shift of the stars in the sky caused by motion of the Earth in its orbit, of the Solar System in its translation through space, or of the stars themselves There is, for instance, the method based on photometry or light measurement

It is an everyday experience that the brilliancy with which lights appear to us, a row of street lamps for example, depends upon the actual brightness of the lamp (its candle-power) and upon its distance from us Similarly, a star's apparent brightness is dependent upon these two factors of real luminosity

and distance Since the apparent intensity of a light varies inversely as the square of its remoteness from us (twice as far meaning one-quarter the light, and so on) it would be a simple matter to determine the distance of a star if we knew both its actual and its apparent output of light

For the purpose of expressing the difference in apparent brilliancy of the stars, astronomers have adopted a scale, the unit of which is called the magnitude, each magnitude differing from the next higher or lower on the scale in the ratio of 2 512 to 1 This number appears rather an awkward one to use but has certain advantages mathematically and is founded on an adopted ratio of 100 between the lights of an average first magnitude star and one five magnitudes fainter In order that a star will shine one magnitude fainter it would require to be put at 1 585 times its previous distance, this number being the square root of 2 512 Or, inversely, a star brought nearer so that it shone one magnitude brighter, would be at about sixty-three per cent of its former distance

These relationships assume that there is an unobstructed passage of light through space For example, if a row of street lamps is observed through a mist or fog, those farthest from the eye are dimmed to a greater extent than those nearer at hand, and we might consider them to be more remote



APEX OF THE SUN'S WAY
The Sun and its attendant train of planets are moving through space at about twelve miles per second The direction of this movement has been computed from the motions of the stars on the sky On the one side of the sky those stars to which we are approaching appear to open out, on the opposite side those we are leaving appear to close up, just as trees appear to do to a man moving through a forest The crosses show the point to which the movement is directed, according to various astronomers

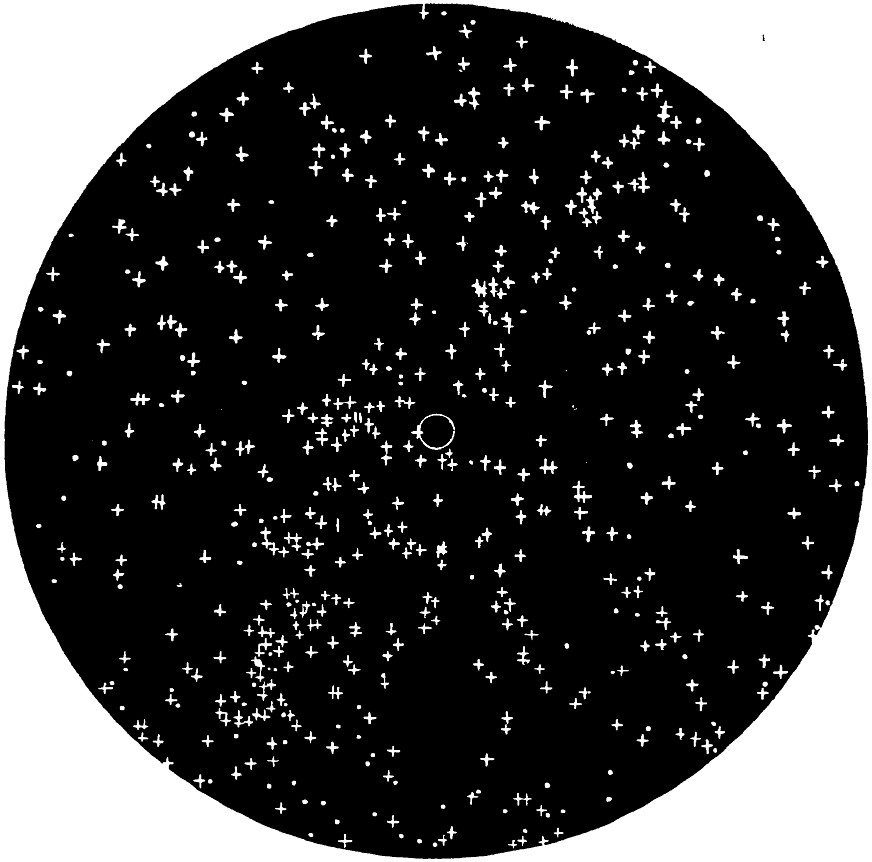


CHART OF HEMISPHERE OF SKY FROM WHICH THE SUN IS RECEDING.

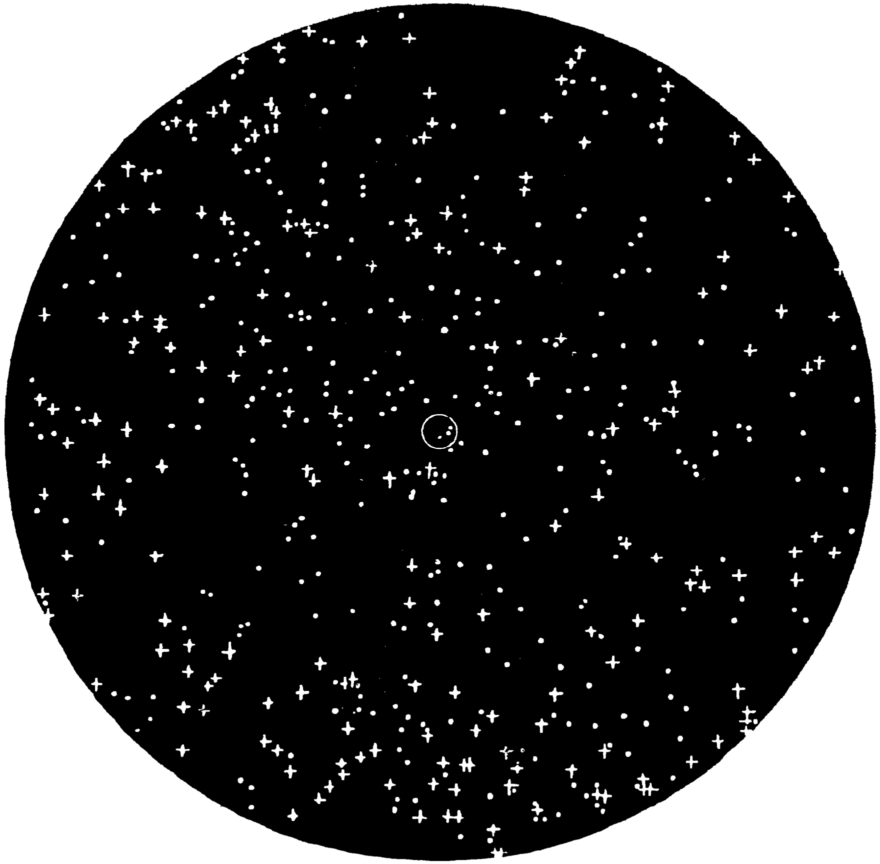
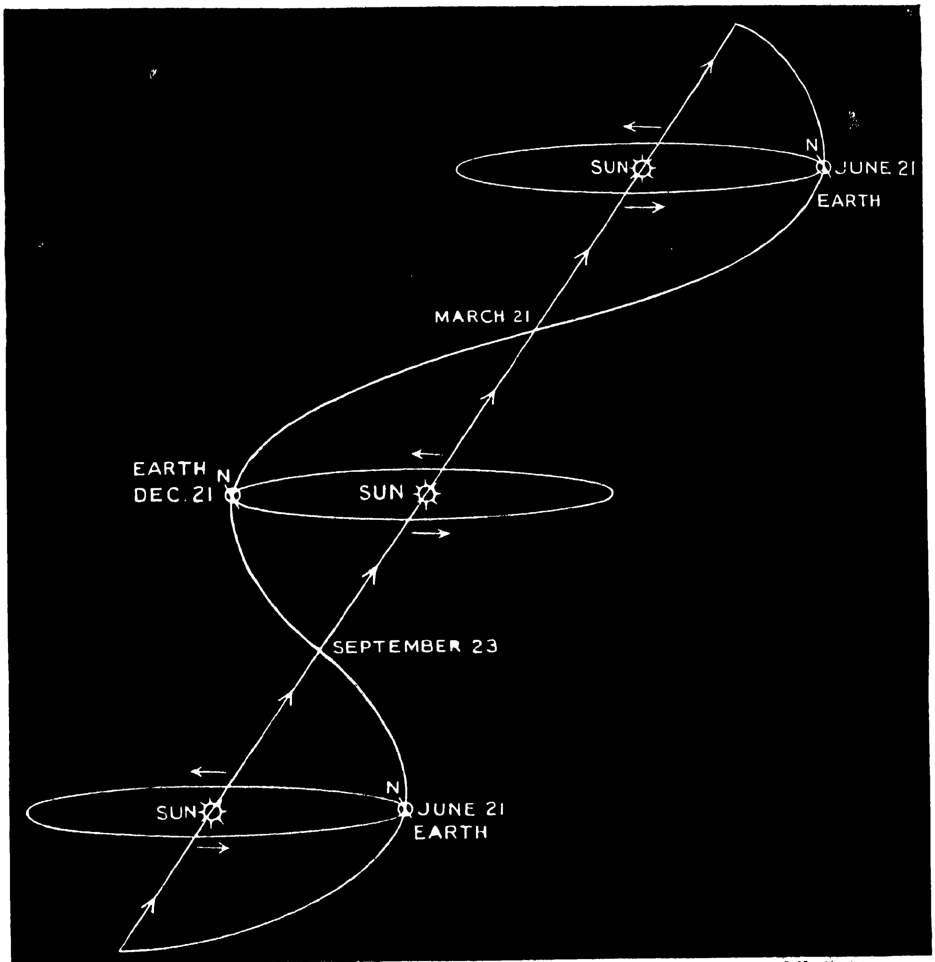


CHART OF HEMISPHERE OF SKY TOWARDS WHICH THE SUN IS MOVING

Distribution of to and fro motions in two hemispheres The motions in the line of sight of nearly 1,000 stars are shown in the two circles above The dots are the stars which have a movement towards the Solar System, the crosses are those which have a movement of recession The motion of translation of the Sun through space is thus well brought out

than they really are if we made no allowance for the absorption of light For some time astronomers were of the opinion that there was evidence of a diminution of stellar light in its transit through space by the action of some sort of celestial fog or through want of perfect elasticity in the æther, but the most recent research would indicate that the loss, if any, is quite inappreciable, except in parts of the sky where certain obscuring clouds are to be found

Until quite recently it was not possible, however, to estimate the parallax of a star by photometric methods There was no means whereby stars could be graded in regard to their true luminosities, all that could be said being that their light outputs varied very greatly from one star to another In the next two chapters, "The Message of Starlight" and "Giant and Dwarf Suns," a description will be given of the modern discovery which enables us to make fairly close estimates of the real luminosity of any star of a particular colour or type of spectrum, and from this development in knowledge, it is now possible to obtain an idea of distance of stars and objects in cases where the remoteness is far beyond the possibilities of direct parallax work Parallaxes found by this method are referred to as "spectral parallaxes" depending as they do on the identification of the spectral types of the stars concerned In the case of stars which are too faint for determination of their spectral type, we are able to determine their colours by the use of coloured screens superposed over specially sensitised photographic plates These colour values can also be related with some precision to luminosity of the stars concerned and information as to distances be thereby obtained

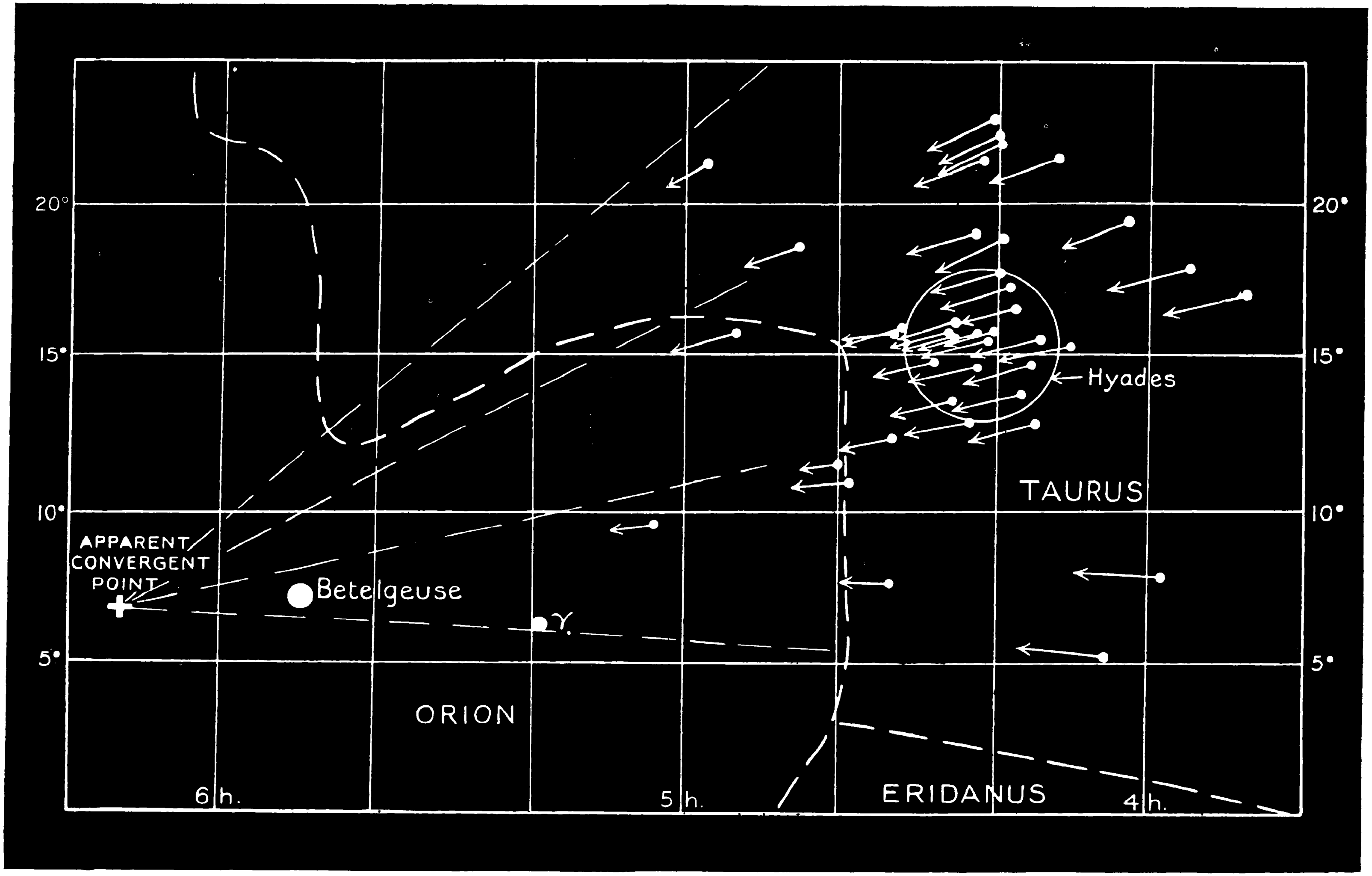


Drawing by] [*W H Steavenson*

THE EARTH'S PATH IN SPACE

The result of its orbital motion, combined with the bodily translation of the Sun and the whole Solar System, is that the Earth's path in space, relative to the visible heavens as a whole, is in the nature of a helix, or corkscrew The considerable extent of the solar motion in a single year is shown to scale on the above diagram, and it will readily be seen that it must provide a very respectable base line for parallax determinations after the lapse of a number of years

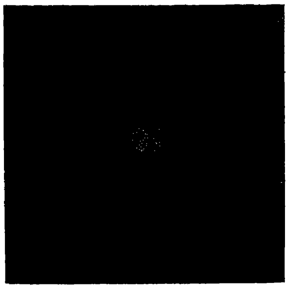
Another indirect method of the greatest value and importance is that devised by the American astronomer W S Adams, of Mount Wilson, California From an examination of the spectra of stars



TAURUS MOVING CLUSTER

About forty stars are known to have apparent converging movements towards a point east of the bright red star Betelgeuse. By these movements and the velocity in the line of sight measured by the spectroscope, the distance of the group has been found to be such that light takes 130 years to travel from these stars to us

of known distances it has been found that the intensities of certain of the lines in their spectra vary with the true luminosity of the star. If these lines are studied in the spectra of stars for which the distance is required, the real light output can be closely estimated, and this, in conjunction with the star's apparent brightness, at once furnishes the data for computing the distance. We have here a method which, although depending fundamentally on direct parallax determinations for its scale, enables us to get knowledge of distance. It is not limited, as in the case of direct parallax determination, by the length of a base line, but is applicable to stars, however distant, providing they are bright enough to permit of photographing their spectra on a sufficiently extended scale, and obviously the limit here is size of telescope which is much more easily got over than inadequacy of base line. Over 2,000 stars have been dealt with in this way, the values got having been given the designation "spectroscopic parallax."



A "PLANETARY" NEBULA
This type of nebula consists of a shell or globe of gas, generally with a star-like nucleus at the centre. The presence of this nucleus affords for measurement a well-defined point, such as is lacking in most other types of nebulae. Hence it has been possible to measure the parallaxes of several "planetaries." The distance of the one above is found to be about 160 light years.

An approximate parallax for a binary star, in which relative movement of the two components has been observed, can be calculated from a law connecting the masses of such systems with their times of revolution and the distances apart of the constituent bodies. The period of revolution being known, the masses are assumed to be comparable with that of the Sun, or of similar binaries for which the distances have been measured and the masses calculated, and the linear distance between the components can then be computed. The angular separation of the stars is measured and knowing the linear dimension to which this angle corresponds, the parallax is derived. As the value thus obtained depends on an assumed mass, it is only approximate and is termed a "hypothetical" or "dynamical" parallax.

Another class of stars for which parallaxes can be indirectly derived are the variable eclipsing binary systems. For these objects, which will be described in the chapter on Variable Stars, the diameters of the two stars can be calculated from the shape of the curve of light variation. The intensity of surface brightness, or light emitted per unit of surface area in comparison with the Sun, can be estimated when the spectral type has been

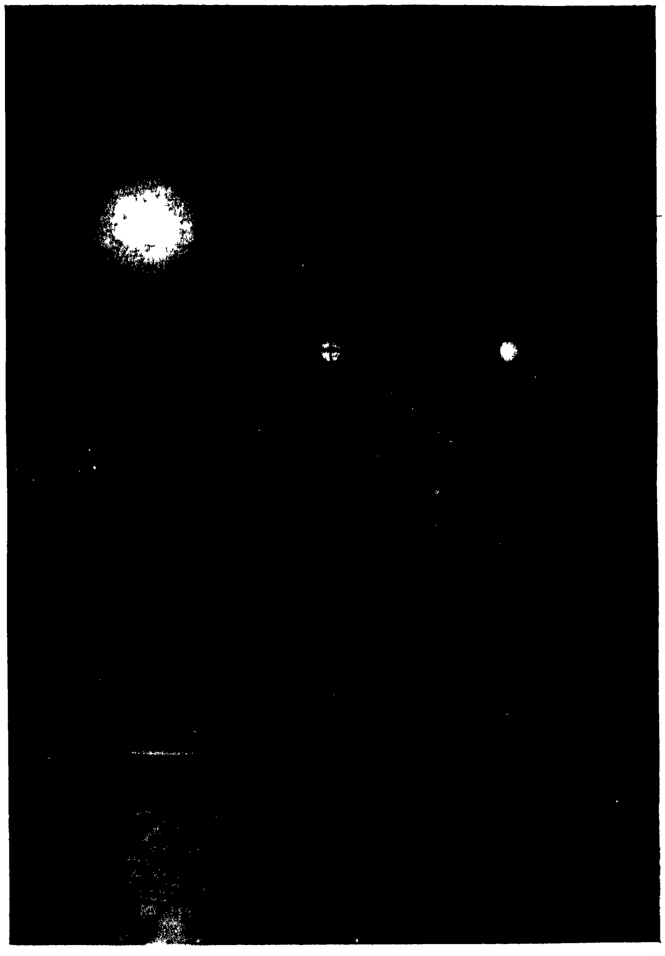


Photo by] [*Judges' Ltd*

DISTANCE AND LUMINOSITY
The apparent luminosity of a source of light varies inversely as the square of its distance from the observer. Applying this rule we can estimate the distance of a star (or lamp) if we know its real brightness, or, conversely, we can deduce the latter if we know the distance. Both applications of the law are in use by astronomers in the determination of the distances and "absolute magnitudes" of the stars.

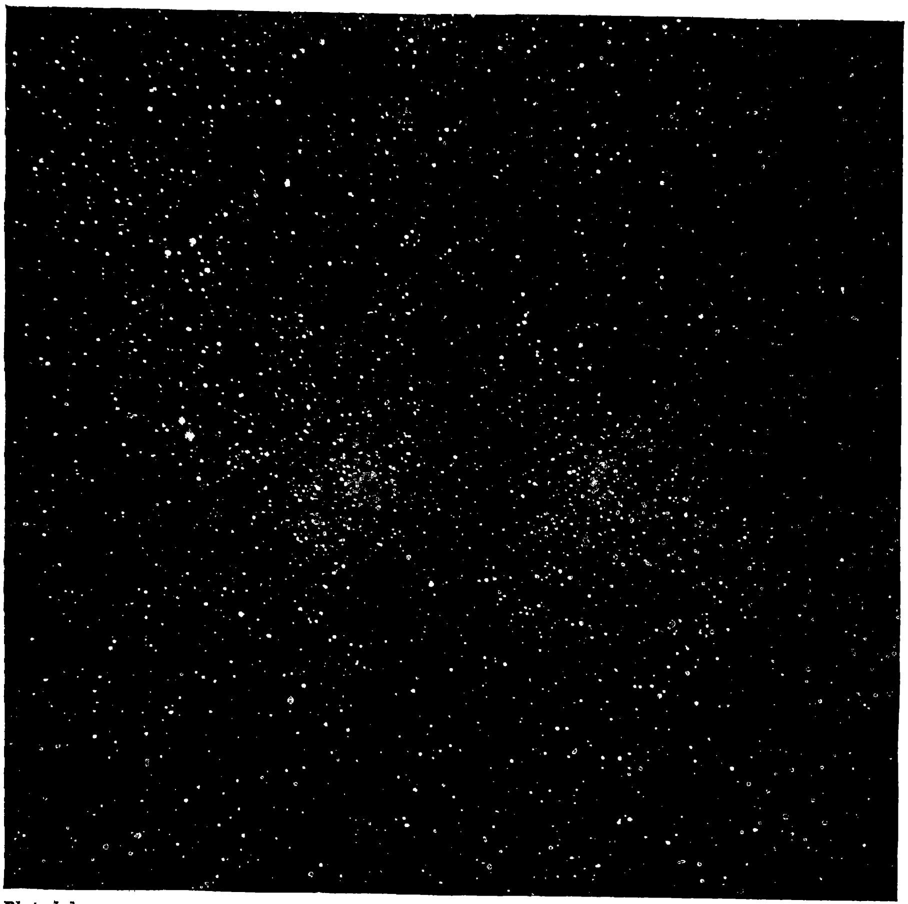


Photo by] [Isaac Roberts

THE GREAT CLUSTERS IN PERSEUS

These two objects, which are together visible to the naked eye as a misty patch, are among the finest examples of the "open" type of stellar clusters Like most others of their class they are situated in the course of the Milky Way, and are characterised, as distinct from the "globulars," by the great brightness of their component stars, which are also more loosely and irregularly distributed

ascertained From the calculated diameters the areas of surface are computed and these in conjunction with the intrinsic surface brightnesses give the total light output in terms of the Sun's The apparent brightness being known, we then have the necessary information for deriving a hypothetical parallax In this way, estimates of the distances of nearly two hundred eclipsing pairs of stars have been secured, most of which are too remote for direct parallax measurement

The indirect methods are used in estimating the remoteness of such objects as the obscuring clouds, globular clusters, and the Milky Way clouds of stars In the case of the obscuring clouds the task of measuring the distance of such indefinite and amorphous masses might appear beyond our powers However, the very circumstance by which the existence of these clouds is revealed provides a means, namely, the deficiency of stars in the sky In the case of one which covers about seventy square degrees of the northern part of Taurus, counts of the stars have been made which show a marked drop in the number per square degree inside its confines The stellar density is found to be only one-fifth of what it is in the immediately surrounding parts of the sky, and the reduction in the brightness of the stars can be calculated from this deficiency in numbers, and also the distance of the stars on the nearer side which are not affected These calculations indicate a distance of about 500 light-years There are some stars involved which are abnormally red in comparison with others elsewhere of the same spectral type, and this is supposed to be the effect of the cloud, which, like fog, is thought to be likely to redden stars seen through it The minute directly measured parallaxes of these stars agree as well as could be expected with the distance derived from the counts of stars

Another obscuring mass of great interest is situated on the borders of the constellations Ophiuchus and Scorpius Here the parallax has been estimated from the deficiency in numbers of a particular type of star, the hot white B type These are relatively scarce in this region for the grades fainter than

about the sixth magnitude Now this type of star is one for which the real luminosity is fairly constant from one star to another and the value is well known Assuming that the relative absence is due to the screening effect of the cloud, the distance is calculated to be approximately 800 light-years

The distances of the luminous nebulæ have been found in some cases by studies of the stars with which they are connected For example, in the case of the great nebula in Orion, the stars in that constellation are believed from their proper motions and luminosities to be about 600 light-years away, and the nebula is obviously connected with many of them Certain forms of nebulæ, known as the planetary type from their planet-like disc shape, have central stars which can be made the subject of direct parallax measurements with powerful photographic telescopes They can also be measured for proper motion, and an idea of their average parallax then obtained Certain of the larger ones are situated at distances of from about 80 to several hundred light-years, while the average for over

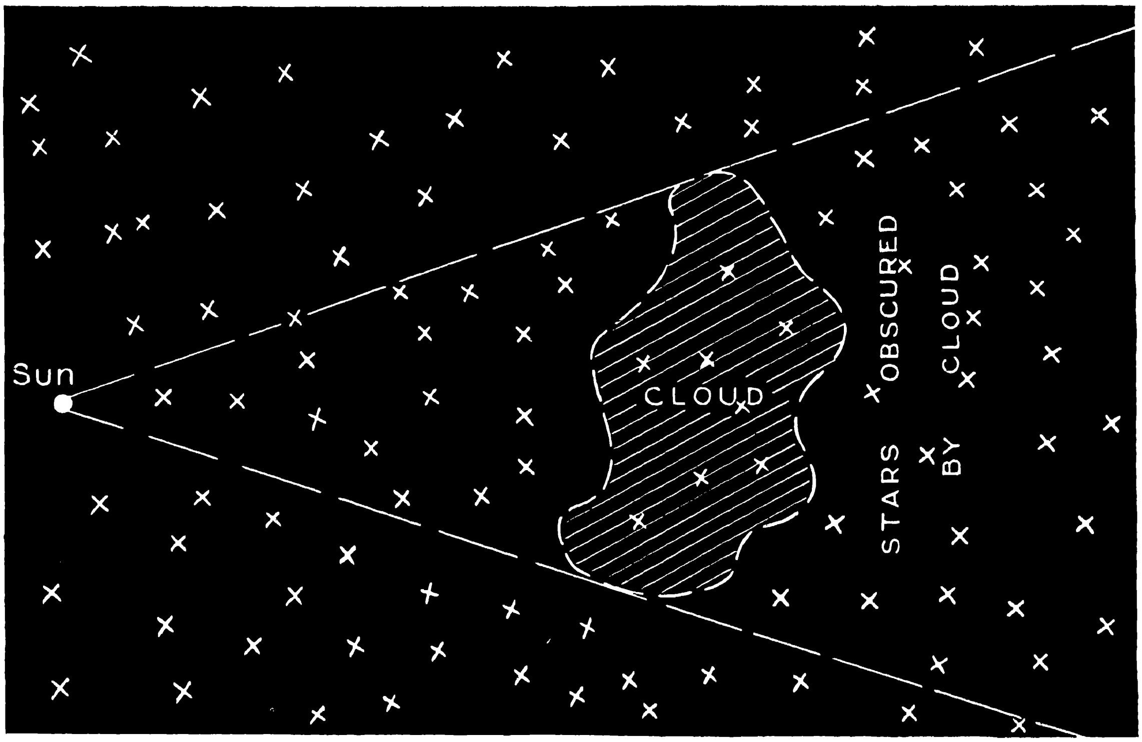
Photo by] [E E Barnard

THE GREAT STAR CLOUD IN SAGITTARIUS

This great mass of stars forms one of the brightest sections of the Milky Way The close aggregation of the stars is in part only apparent, being due largely to their great distance and to the fact that we are looking through a stratum of considerable depth A recent estimate of the distance of this star cloud is 200,000 light-years Other portions of the Milky Way are still more remote, perhaps as far as 400,000 light-years

seventy whose motions are known is about a thousand light-years as found by the method of proper motions and radial velocities described in a preceding paragraph

With regard to the problem of the distances of star clusters, so remote that even the lapse of a long period of time does not show any apparent change of position in the sky, this is attacked by various indirect methods which are mainly based on photometric studies of the included stars There are two general types of star cluster the open or loose type, and the globular cluster The former are all near the plane of the Milky Way, and are situated at very varying distances from us which are not known with any degree of precision except for such nearer objects as the Pleiades or Hyades The estimation of the parallaxes of globular clusters cannot be based on the direct geometrical methods, the order of remoteness is far too great for this By comparison of the magnitudes of the brightest stars in them with those of the same spectral type or colour in the neighbourhood of the Solar System, distances



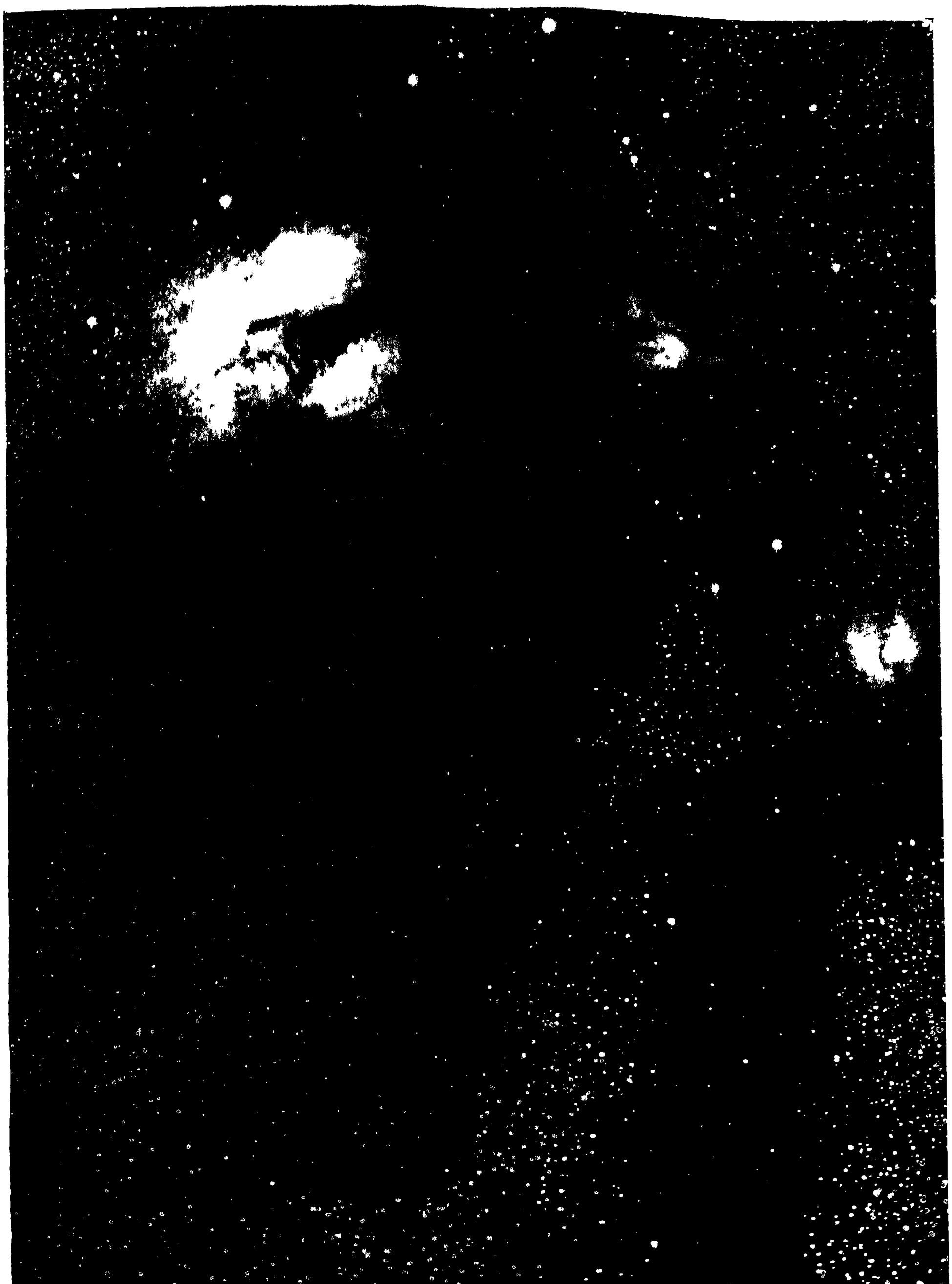
ESTIMATING THE DISTANCE OF AN OBSCURING CLOUD

Many dark markings on the sky, due to clouds of dust and gas which absorb the light of the stars beyond them, are known The distances of several have been estimated from their effect in reducing the number of stars visible as compared with those in surrounding parts of the sky

have been derived by modern workers Another method used is founded on a remarkable law connecting the luminosities of a particular type of variable star (the Cepheid), common in the globular clusters, with their periods of variation, which will be described in the chapter on Variable Stars From the distances thus derived a similarity in the actual diameters of the globular clusters has been found The remoteness is thus directly proportional to the apparent angular diameter of the cluster and this can be applied to finding the parallaxes for the smaller and fainter objects of the class whose individual stars have not yet been studied The distances obtained from these methods by the American astronomer Dr Harlow Shapley, of Harvard College Observatory, are exceedingly great, and much in excess of what has been believed since the time of Sir William Herschel, who also favoured very great remoteness for these objects, although, perhaps, on inadequate observational material Shapley's distances, which are now generally thought to be of the correct order of magnitude, vary from about

21,000 light-years in the case of the nearest (Omega Centauri) to about 220,000 light-years for the most remote

To observers in the southern hemisphere, there are visible to the naked eye two nebulous spots of light, not unlike portions of the Milky Way although appearing some distance in the sky from the galactic circle, known as the Magellanic Clouds or Nubeculæ From the known luminosities of some of the stars in them, particularly the bright white stars and the Cepheid variables, and also from the angular diameters of some globular clusters situated in the greater Cloud, the distance and diameter have been estimated at 115,000 and 15,000 light-years respectively for the larger, and 65,000 and 5,000 light-years for the smaller Cloud These objects are possibly universes separate from the main stellar system and contain stars, clusters and nebulæ of varied types



From] [" *Knowledge* "

DARK CLOUDS NEAR RHO OPHIUCHI

The distance of these markings, and of the luminous nebulae which are probably connected with them, has been estimated by several astronomers From their obscuring or screening action there is a relative deficiency of the hot white B type stars, the distances of which are approximately known By this criterion Dr Shapley of Harvard College Observatory has derived a distance for the clouds of between 650 and 1,000 light-years

The distances and constitution of the spiral nebulæ are matters which are as yet the subject of considerable controversy Some astronomers consider these bodies to

be separate universes of stars, basing this conclusion largely on their spectra, which resemble that of a star or of a compressed cluster of stars, and also on the appearance of temporary stars in them, which if of the same order of luminosity as those appearing elsewhere in the sky would indicate distances of millions of light-years Other astronomers, however, believe them to be composed of dust and gas shining by reflection from the stars included in them, the distances being comparable with those of the globular clusters Van Maanen has lately shown that motion of the various portions of certain spirals can be detected after an interval of only a few years, and, if the actual velocities are of the order of those observed elsewhere in the heavens, motion could hardly be manifested in so short a time at distances greater than a few thousand light-years The final solution of the problem of their distances is for the future, but the present trend seems towards the smaller values

EDMUND HALLEY (1656-1742)
Second Astronomer Royal (1719 1742) and a contemporary and friend of Newton He discovered the periodicity of the comet bearing his own name and the proper motions of several of the "fixed" stars He also devised a method of measuring the Sun's distance by observation of Transits of Venus across the solar disc One of his greatest services to science consisted in persuading Newton to publish his immortal gravitational discoveries

The distance of the confines of our universe of stars has been estimated by various astronomers by methods based chiefly on the luminosities of stars Assuming that the faintest stars photographed in the Milky Way are comparable in real output of light with the brightest orbs in the neighbourhood of the Sun, the farthest limits must be tens of thousands of light-years distant Dr Shapley has shown that the globular clusters are evidently part of our universe and that the Milky Way seems to be co-extensive with the system of these clusters If so, the diameter of the stellar system is probably something like 300,000 light-years The consideration of this, however, belongs more properly to the question of the Structure of the Universe, which will be dealt with in a later chapter One remarkable feature of the sky as it presents itself to us is worthy of reference With the naked eye on any clear night, we are looking at the inhabitants of space, *not* as they exist at the moment of observation, but as they existed at various past times up to about 2,000 or so years ago! This is because the individual stars visible to unaided vision are at distances ranging up to something like 2,000 light-years With the aid of even a small telescope the range in past time is certainly tens of thousands of years—it may indeed be millions!

CHAPTER XII

THE MESSAGE OF STARLIGHT

By HERBERT DINGLE, B Sc , F R A S

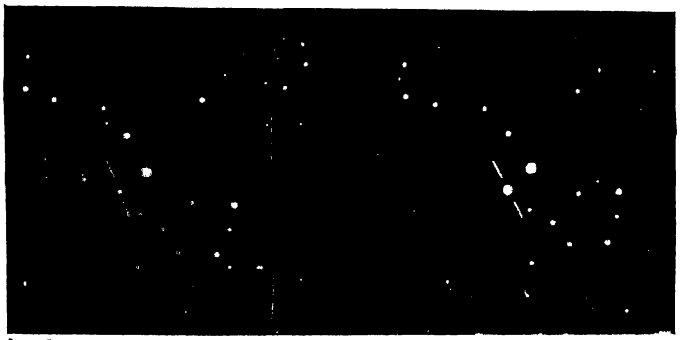
IT is remarkable that the stars and planets, though to the eye they appear almost indistinguishable, have actually scarcely a feature in common If one runs in mind through the various characteristics of the heavenly bodies in which the astronomer is interested—size, mass, movements, temperature, brightness, and the rest—the differences, without exception, are almost as great as it is possible to conceive To the ancients, of course, these differences were unknown In calling a few of the heavenly bodies " planets "—that is, " wandering stars "—they called attention to the one clear point of distinction which they could establish between those bodies and the stars—their movements were different It had to be left to modern times—and, in the main, to the second half of the last century—to show how radically distinct were the two types of body

Photo by] [*Cambridge Observatory*

FOUR PRISM SPECTROGRAPH OF NEWALL TELESCOPE

The Newall Telescope, when it was erected, was the largest refracting telescope in the world It is now at the Solar Physics Observatory at Cambridge

For a time, indeed, it seemed as though the chief effect of the advance of knowledge, so far as the stars were concerned, was to emphasise our ignorance In very early times, the relative distances of the brighter planets were known, but not those of the stars To the early astronomers the stars were all at the same distance—how great, none could measure—embedded in a crystalline sphere which revolved with absolute precision once a day round the Earth Later, during the Renaissance period, when the form and laws of working of the Solar System were discovered, the stars still preserved their mystery The labours of Tycho Brahe and Kepler, the telescopic observations of Galileo, and even the genius of Newton, alike failed to throw the faintest light on the problem of the stars The great forward movement in astronomical thought which took place at that time not only told us nothing about them , it took away even the little which we thought we knew before It showed that the diurnal movement of the stars was not a real movement at all, but an illusion arising from the daily rotation of the Earth on its axis , it was not the stars that moved, but we ourselves The telescope, which had revealed so much in our own Solar System, could do nothing with the stars It showed them still as points of light—brighter, it is true, and increased in number, but without the slightest hint of magnification There was no perceptible change of position of the stars as the



From] [*" Astrophysical Journal "*

PHOTOGRAPHS ILLUSTRATING COLOUR INDEX OF A STAR

Stars whose images appear of the same size on the two plates are bluish-white stars The star (μ Cygni) which appears much larger on the right-hand plate is a red star

Earth moved across many millions of miles in its orbit—an indication that the stars were exceedingly distant, but entirely devoid of anything more definite We were left with a sky peopled by unnumbered, immovable, unmeasured points—a series of negatives with no apparent sign of a positive

And yet all the time there was a positive, so obvious as to be overlooked, and yet so exceedingly significant that we can see no limit to the knowledge that it is able to bring to us We might have added the word " luminous " to our list of adjectives, and by so doing have taken the whole sting out of the array of negations For, in the fact that a star emits light lies the possibility of the latest and most extensive branch of Astronomy—Astrophysics The planets also send light to us, but not their own light They reflect the light of the Sun, and so, in the most important characteristic of all, we see that they and the stars are unlike one another We can study the planets because light shines on them, we can study the stars because their light shines on us

The message of starlight is delivered in three more or less distinct ways It is embodied, first of all, in the total amount of light we receive from a star, or (a closely related quantity) the total amount of light which the star sends out in a given time Secondly, there is a message in the colour of that light Stars, as we know, differ greatly in colour, from the red glare of Antares or Betelgeuse to the clear bluish-white glow of Rigel or Regulus Finally, and most striking of all, there is the structure, or spectrum, of the light We must consider briefly how these three characteristics of starlight have opened up a new heaven to the watchers of the skies

The principles and methods concerned in measuring the apparent brightness of the stars will be fully discussed in a later chapter It will be sufficient here to say that astronomers have adopted a regular classification of the stars according to their brightness, as seen from the Earth The divisions of this classification are termed " magnitudes," and each of these is numbered according to its order in the scale Thus the brightest stars are said to be of the " first " magnitude, while the faintest visible to the naked eye are classed as of the " sixth " Stars of any one magnitude bear a definite relation to those of the next below, being almost exactly two and a half times as bright This rule is extended to the telescopic stars, where magnitudes even as low as the twenty-first are within the range of powerful instruments

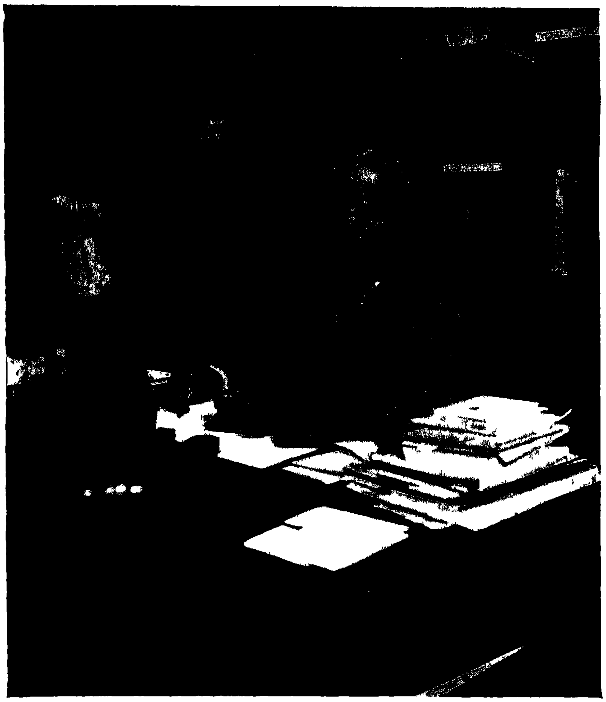


Photo by] [*Messrs Russell & Son*

SIR JOSEPH NORMAN LOCKYER, K C B, F R S

Sir Norman Lockyer was one of the pioneers of Astrophysics, and was the originator of the modern view that stellar spectra are determined mainly by temperature His work covered the whole field of Astronomy He was the founder and editor for fifty years of the scientific journal, " Nature "

There is no fundamental difficulty in measuring the apparent magnitude of every star that can be photographed, the one thing necessary is time Unfortunately, that is not true of the real brightnesses of the stars A knowledge of the real brightnesses of the stars involves a knowledge of the distances, and this, unfortunately, we possess for comparatively only a very few stars It is known that, if a source of light be placed at varying distances from the eye, its apparent brightness will vary as the inverse square of the distance For example, if a star has a certain apparent brightness at a certain distance, it will appear only one-quarter as bright if it is removed to twice the distance Suppose, then, that we know the distances of a number of stars, and have measured the

apparent brightnesses. We can then calculate relatively how bright the stars would appear if they were all brought to the same distance from the eye, and it is clear that their apparent brightnesses in that event would represent their real brightnesses, for the effect of varying distance would be eliminated. A standard distance of ten parsecs (parallax 0.1 second of arc corresponding to a distance of 190 million million miles) has been chosen, and the apparent magnitude which a star would have at that distance is called its *absolute* magnitude. It is clear that in the absolute magnitude of a star we have some information about the character of the star itself.

It appears that the absolute magnitudes of stars vary over almost as wide a range as their apparent magnitudes. There are stars 10,000 times as bright as the Sun, and others which, even at the standard distance, are too faint to be detected by virtue of their light. This is exceedingly important, for it assures us that, whether or not the stars were all alike at birth, there are certainly very wide differences between them now. Moreover, there is a perfectly gradual transition in brightness from one extreme to the other. It is not a question of a few stars being very much brighter or very much fainter than the great uniform majority. Every stage of luminosity, from the highest to the lowest, is well represented, so far as can be ascertained from the limited amount of information that has been accumulated with regard to absolute stellar magnitudes. Evidently we are here in the presence of knowledge of very great importance. We must leave for a future chapter, however, the discussion of its meaning. At present it will be sufficient to remark that it must be taken in conjunction with other messages of starlight before its full significance can be realised.

Photo by] [*Lafayette*

PROFESSOR ALFRED FOWLER, F.R.S.

Professor Fowler, of the Imperial College, South Kensington, is one of the greatest of living authorities on Spectroscopy as an independent science and as a branch of Astronomy. He has made many contributions to the interpretation of stellar spectra, and to the study of atomic physics.

Turning now to the question of colour, probably the first thing that will strike us is that there seems to be no possibility of measuring the colour of a star and expressing it by a number, as we saw was done with respect to brightness. In this, however, we are wrong. In the early days of colour measurement, such a classification was attempted by constructing a rough arbitrary scale, in which the bluest stars were numbered 0, and the reddest 10, and the numbers were assigned according to the judgment of the observer. Here, it is true, there was no possibility of precision or freedom from individual bias, and although such a classification was better than none at all, very little definite meaning could be attached to the colour-number of a star. At the present time, however, a much more delicate method of colour measurement is adopted; in fact, three distinct methods have come into general use, and the results which they give are quite consistent with one another. The colour of a star is expressed by its *colour-index*, its *effective wave-length*, or its *exposure-ratio*. We will see briefly what each of these terms means.

The estimation of colour by means of colour-index depends on the fact that the apparent magnitude of a star, as we have defined it, is determined, not only by the brightness of the star and its distance from us, but also by the instrument which is used to receive the light which the star sends out. We might, for example, compare the star under examination with a standard star by means of the eye or by means of photography, and the results we obtain might differ widely, in a manner depending only

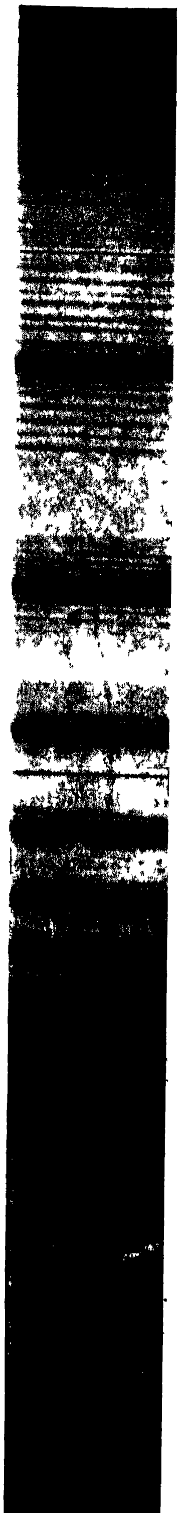


Photo by [Huggins

SPECTRUM OF VEGA

This is a typical spectrum of Harvard Class A. The very strong absorption lines, forming a regular series, are due to hydrogen. Sirius and Castor are other examples of stars having this type of spectrum.

on the colour of the star. For, as we know, the eye is sensitive to the whole of the visible spectrum, whereas an ordinary photographic plate is scarcely affected by the red, yellow, and most of the green rays, but, on the other hand, registers the ultra-violet light, which the eye cannot see, as well as the visible blue and violet light. If, therefore, a star has most of its radiation near the red end of the spectrum, it may appear as a bright red star to the eye, but as a very faint object on the photographic plate. A star having most of its radiation in the blue, however, may appear bright to both eye and plate, or, if the radiation extends in strength far enough into the ultra-violet, the star may even appear brighter to the plate than it does to the eye. The difference evidently depends on what region of the spectrum contains the greatest part of the radiation from the star, which is simply another way of saying that it depends on the colour of the star. Accordingly, the difference, *photographic* minus *visual* magnitude, is a direct measure of colour, and is therefore known as the star's *colour-index*. If the difference has a large positive value, the star is very red (remember that, the brighter the star, the smaller is the number representing its magnitude); if, on the other hand, the difference has a zero or negative value, the star must be blue. Colour is thus estimated on the same scale—the scale of magnitudes—as is brightness. Since a direct comparison between the photographic and visual scales is not possible, the "zero-points" of the two scales have to be chosen independently. They are, by common agreement, made such that a certain defined type of blue star has a zero magnitude on each scale. The way is then clear for the determination of colour with the same degree of precision as that achieved in the measurement of brightness.

A second method of colour estimation is the direct determination of the region of the star's spectrum which most strongly affects a photographic plate sensitised for all colours. A spectrum of the star is obtained with exceedingly small dispersion, so that it looks very little different from the direct photograph of the star itself. This spectrum will affect the photographic plate most strongly at the point corresponding to the light in it which has the greatest intensity, and therefore which has the greatest effect in determining the colour of the star. The wave-length of the light at this point is called the *effective* wave-length; the larger the effective wave-length, the redder is the star. It is found that the relative colours of two stars, as determined by colour-index and by effective wave-length, are, in general, in the same order, and the two methods are therefore consistent with one another.

The third method—that of exposure-ratios—is due to Professor Seares, of the Mount Wilson Observatory, who has done a great deal of very valuable work in connection with the standardisation of magnitude and colour measurement. Two photographs of a star are taken—one on an ordinary photographic plate, and the other on a plate which is sensitive to the whole of the visible spectrum, and is arranged, by combination with suitable light filters, to record images having the same relative intensities as those estimated by the eye. The latter kind of plate can evidently be substituted for the eye in the determination of visual magnitudes, and it is, in fact, so used. Its scale of magnitudes is called the *photovisual* scale, and is superior to the visual scale in two respects—first, it is independent

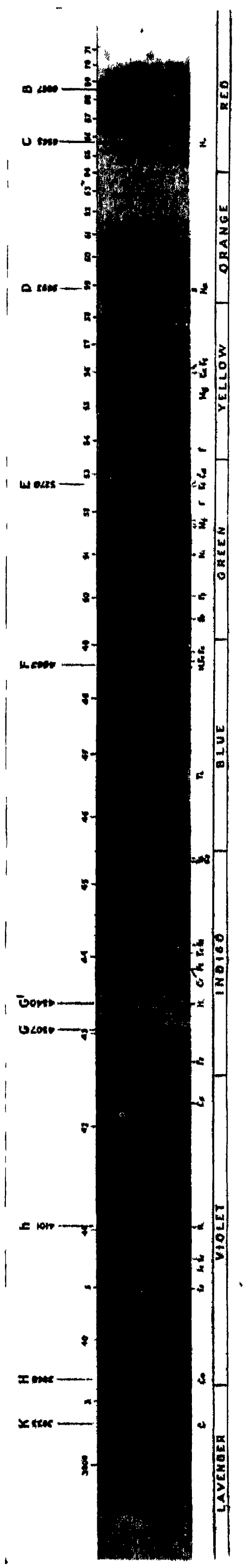
of the peculiarities of particular observers, and, second, it extends the application of the measurements to stars too faint to be seen by the eye For the determination of colour by the exposure-ratio method, however, magnitudes are not directly measured The two plates mentioned above are exposed successively to the same star under exactly the same conditions, and the colour is measured by the ratio of the times of exposure necessary to produce images of the same intensity on both of them It is clear that a red star will take much longer than a blue star to impress the ordinary plate as strongly as it does the photovisual one, so that it will readily be understood that the method gives an actual criterion of colour

When the results of colour measurement are analysed, it is found that, as with magnitudes, there is a gradual transition from one extreme to the other From the reddest stars, which Secchi, in the middle of the last century, likened to drops of blood, to the bright blue stars found in the constellation of Orion and elsewhere, there is a continuous range of colour, without a break and without a marked preponderance of stars of any one colour This is another example of the continuity of phenomena which is one of the most significant facts of modern Astronomy, as it was shown to be more than sixty years ago in the realm of Biology

But we must hasten to the consideration of stellar spectra, which are, after all, a more detailed and analytical statement of the colours of the stars The spectrum differs from the other two qualities of starlight in being an essentially modern discovery Magnitudes were measured in the time of Ptolemy Colour, though no attempt seems to have been made to classify it at so early a time, was noticed as a characteristic by which the stars could be partially distinguished But it was not until the beginning of the Nineteenth Century that the spectrum of a star was first seen, and no serious study of stellar spectra was undertaken until the middle of that century, when Secchi, Huggins, Rutherford and others inaugurated the new era in which we are now thoroughly immersed

At the very beginning of the work it was noticed that the spectra of the stars were not all the same Some stars gave spectra almost indistinguishable from the spectrum of the Sun, while others gave quite a different kind of spectrum Vega, for example (*see* page 482), appeared to show only a regular succession of very pronounced dark lines, most of which had never been matched in the laboratory at all A new field of activity was opened up in the accumulation and classification of as many stellar spectra as possible

In spite of the variety of the results obtained, there was one striking uniformity—the overwhelming majority of the stars gave spectra of the absorption type, that is, a background of continuous spectrum on which dark lines appeared What this meant has been explained in Chapter I, a star evidently consisted of a very hot central core emitting light which alone would form a continuous spectrum, surrounded by a cooler, but still luminous, atmosphere, which absorbed certain rays from the light of the interior and thereby gave rise to the dark lines perceived The almost universal



THE SOLAR SPECTRUM

The solar spectrum is a typical spectrum of Class G The hydrogen lines (marked C, F, G′, *h*) are not nearly as conspicuous as they are in the earlier classes, while the two lines H and K of calcium, are exceedingly intense

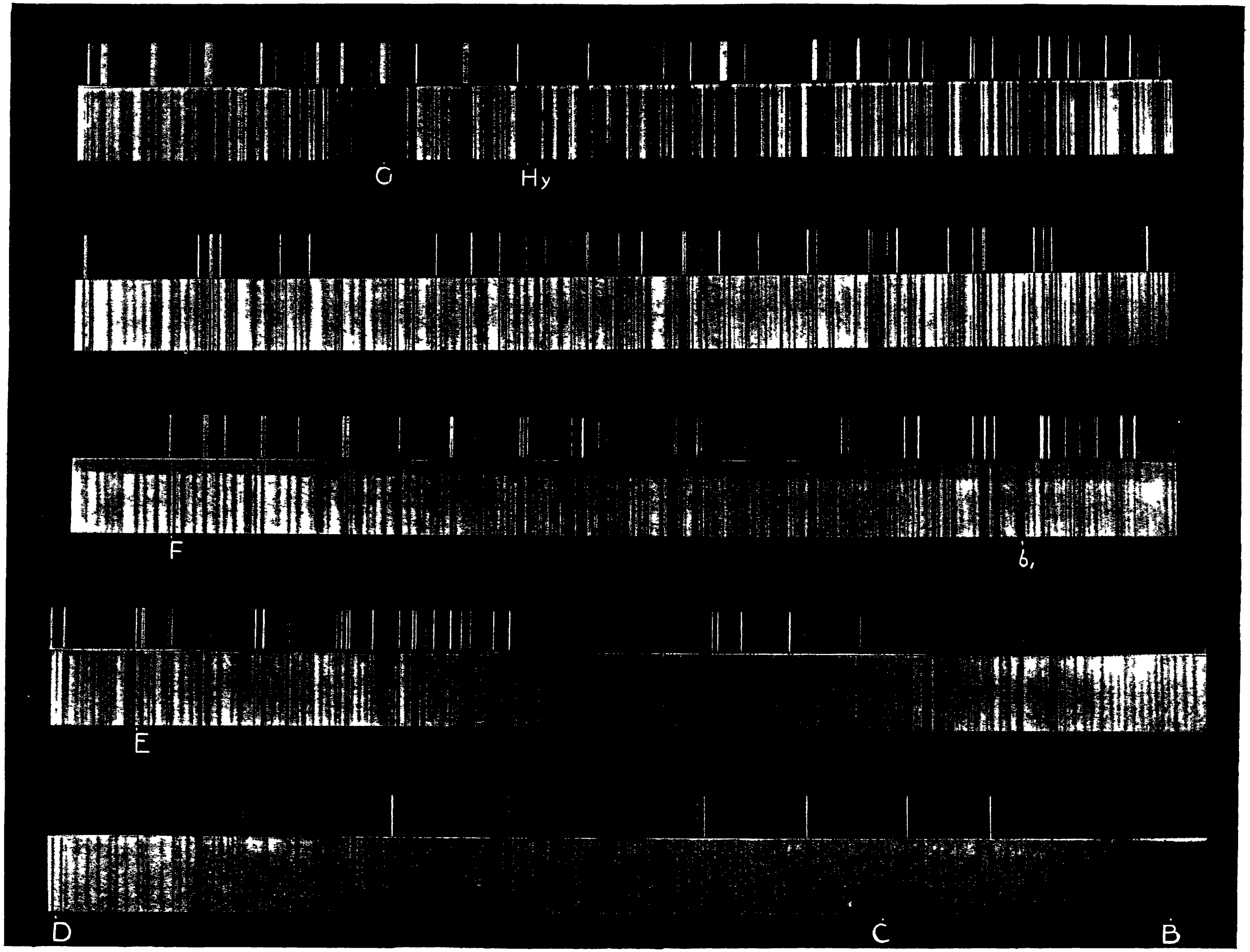


Photo by] [Mount Wilson Observatory

SPECTRA OF THE STAR ARCTURUS AND IRON

The upper spectrum is the spectrum of iron taken in the observatory, and the lower is the spectrum of Arcturus Arcturus has a spectrum of Class K—a little later in the Harvard sequence than the solar spectrum The presence of iron in the star is clearly shown in this picture, and accurate measurements of the positions of the lines show also whether the star is moving towards or away from the Earth The lines marked by letters appear as prominent lines in the solar spectrum

occurrence of this kind of spectrum showed that nearly all the stars, including our Sun, were constructed in very much the same way But there were a few stars which gave *bright* lines on a fainter continuous background In some spectra the bright lines were accompanied by dark ones, while in others they existed alone These bright line stars have, from the moment of their discovery, presented some of the most fascinating problems to the astrophysicist, towards the solution of which very little has yet been done They are known as Wolf-Rayet stars, in honour of the two observers who first detected them We can do no more than mention them here, for they are relatively too few in number to influence, to any great extent, the wider generalisations that are aimed at in the study of the sidereal universe

It was seen, too, at an early stage, that a large number of lines in stellar spectra were identical in position with lines which could be produced from familiar terrestrial substances in the laboratory This meant, of course, that those substances were present in the atmospheres of the stars With regard

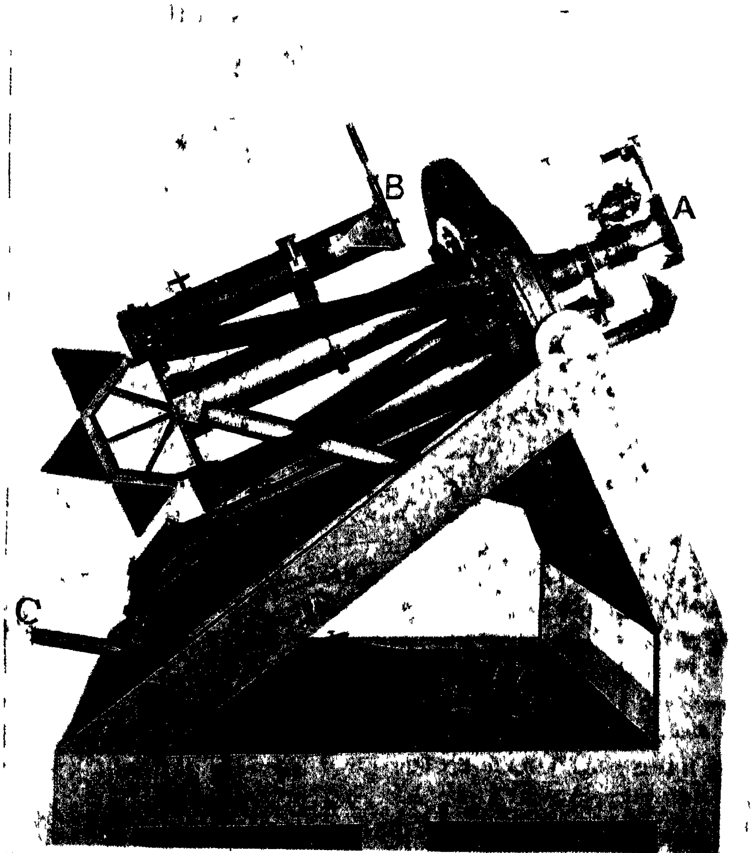
LARGE LITTROW SPECTROGRAPH AT THE IMPERIAL COLLEGE OF SCIENCE AND TECHNOLOGY, SOUTH KENSINGTON

This is a special form of spectrograph used in obtaining high dispersion When used, it is completely enclosed in a long wooden box On the left are the slit and the photographic plate The light entering the slit is sent through the lens and prism and reflected back again, as a spectrum, by a mirror to the photographic plate

to the lines which were left over, there were two possibilities either they were lines of substances unknown on the Earth, or else they were lines producible from terrestrial substances by some method not up to that time devised We can see now that these two possibilities were open, but at the time when the phenomena were first recorded, the second one was not admitted It was believed that the spectrum of an element was unique and unalterable, that no matter how a substance was made to emit radiation, it always emitted the same radiation, in greater or less intensity according to the conditions of its excitation It was Lockyer who first challenged this assumption He showed, by irrefutable evidence, that it was possible to make a single element produce greatly different spectra by raising it to different temperatures, and pointed out that, in consequence of this fact, the spectrum of a substance might be made to indicate, not only the chemical composition, but also the temperature of the substance, within a fairly narrow range We shall have more to say on this point shortly, but for the moment we will observe only that it gave an alternative to the assumption that in the stars

there were many substances unknown on the Earth Later researches have amply justified the belief that this alternative represents the truth At the present time, most of the lines in stellar spectra have been identified, and those that remain over are, for the most part, regarded as lines that will probably in the future be obtained from familiar substances There is very little doubt that essentially the whole of the matter in the universe is formed into the ninety or so elements which are included in the chemist's table

The next point to be noticed was that, despite the variety shown by stellar spectra, it was possible to arrange the spectra in a continuous sequence From one type of spectrum to the next in this sequence, the change was exceedingly small, so that in spectra, as in magnitudes and colours, the law of continuity was seen to reign The way to classify spectra was therefore obviously to divide this unbroken sequence into a number of arbitrary divisions, and to assign to each division a distinctive number or letter The earliest classifications, by Rutherford and Secchi, were based on this principle According to Secchi's system, the spectra were divided into four *Types* Type I comprised the stars with simple spectra, consisting of lines then mostly unknown, but now traced in the main to helium or (as in Vega, which we have previously mentioned) to hydrogen. Type II contained the stars with many-lined spectra, like the Sun The spectra of Type III contained bands, or flutings, which Fowler, in 1903, traced to titanium oxide Type IV contained flutings arising from carbon and its compounds The bright-line stars were subsequently grouped into a Type V



By permission of] *[The Yerkes Observatory*

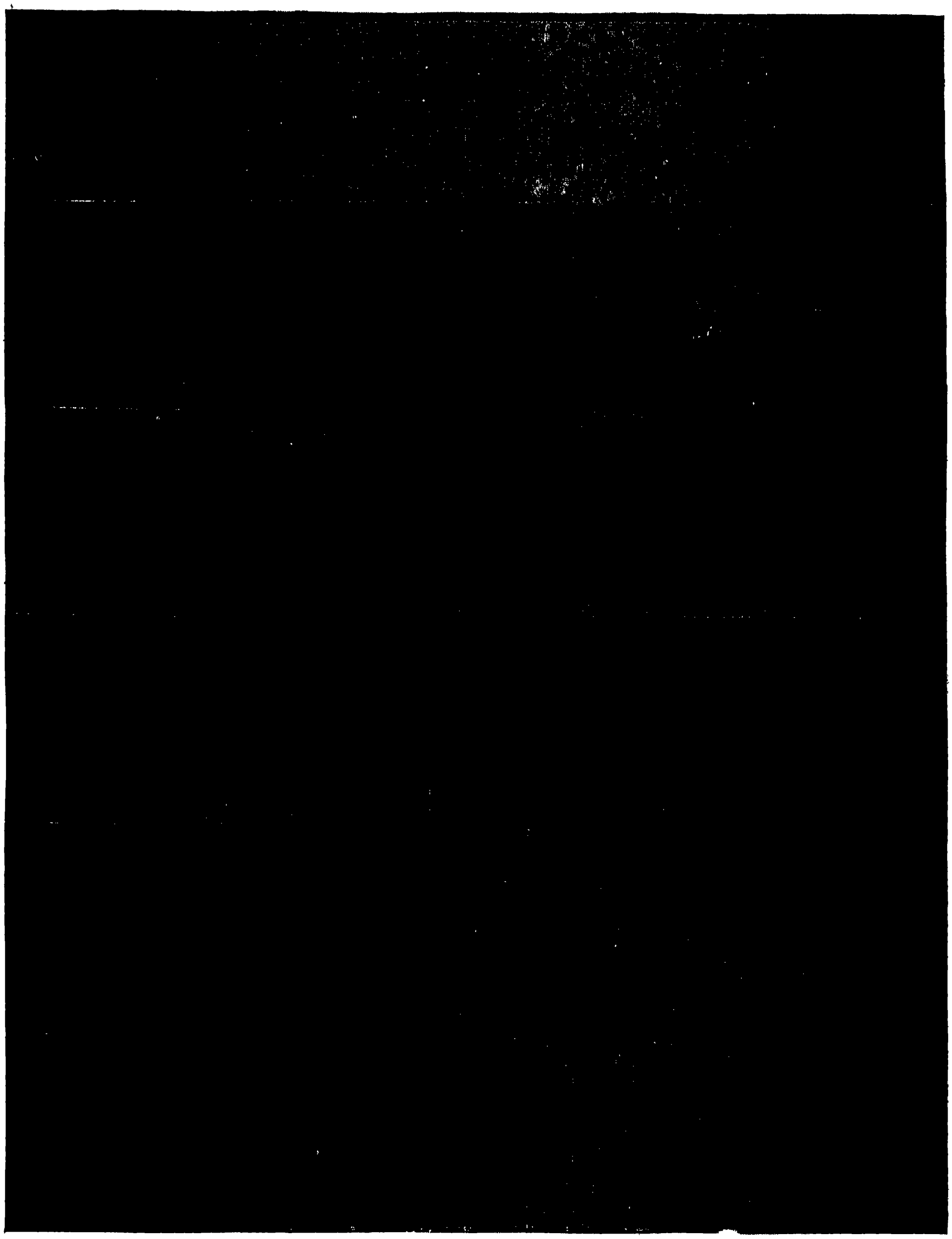
THE BRUCE SPECTROGRAPH OF THE YERKES OBSERVATORY
The image of the star is focussed by the large telescope on the slit at A The spectrum produced by the train of prisms is photographed at B The eyepiece C allows the observer to make sure that the image remains on the slit throughout the exposure

Secchi's classification is still often referred to in astronomical literature, but, for detailed work, it has been replaced by the system adopted at the Harvard College Observatory in an extensive study of stellar spectra undertaken as a memorial to the late Dr Henry Draper This system is generally referred to as the Harvard, or Draper, classification, and the succession of types which it includes is known as the *Harvard sequence* The great majority of the stars fall into six classes, denoted by the letters B, A, F, G, K, M —relics of what was originally an alphabetical arrangement Detailed study shows that there are probably two branches of the main sequence—first, two successive classes, R and N, branching off at G, and second, a small class S, leaving the main sequence at K There remain the bright-line stars, which are included in a class O and placed at the

head of the sequence The complete Harvard sequence of spectra, as it now stands, is therefore as follows —

$$\begin{array}{l} \qquad\qquad\qquad \nearrow R,\ N \\ O,\ B,\ A,\ F,\ G,\ K,\ M \\ \qquad\qquad\qquad\quad \searrow S \end{array}$$

Secchi's Type I corresponds approximately to classes B and A , Type II to F, G, K , Type III to M , and



B — ε Orionis (Alnitam)

A — α Canis Majoris (Sirius)

F — α Carinae (Canopus)

G — α Aurigae (Capella)

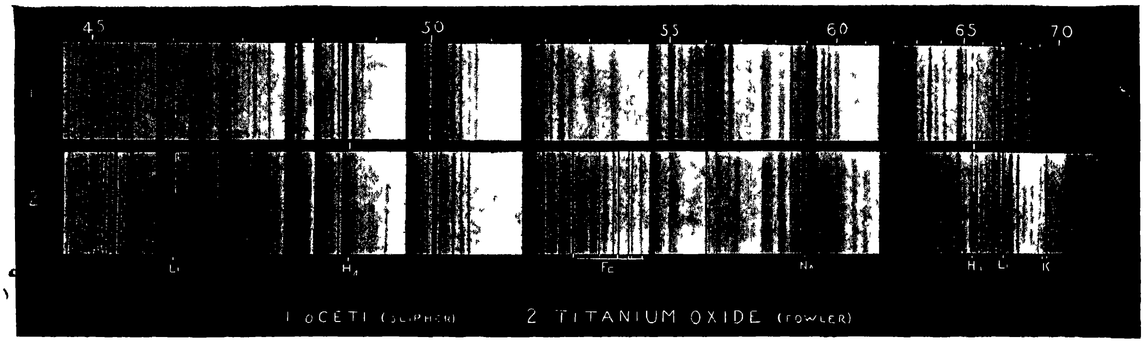
K — α Boötis (Arcturus)

M — α Orionis (Betelgeuse)

Photo by] [*Harvard College Observatory.*

THE CHIEF TYPES IN THE HARVARD SPECTRAL SEQUENCE

Nearly all recorded stellar spectra belong to the type represented in this photograph, or to intermediate types The characteristic lines of the B type are those of helium The strong hydrogen lines in the A type spectrum gradually become weaker in the succeeding types The increasing complexity of the spectra after type F is due to the appearance of multitudes of metallic lines Class M spectra are not well represented in the region illustrated here



SPECTRA OF THE STAR o CETI (MIRA) AND TITANIUM OXIDE
The characteristic feature of spectra of Class M, to which Mira belongs, is the predominance of flutings due to titanium oxide The identity of these flutings was established by Fowler in 1903, and is shown clearly in this photograph

Type IV to N R and S are small classes which Secchi did not distinguish The Sun is a typical star of class G Examples of these types are shown in some of the illustrations With regard to the illustrations in which the gradual transition is not obvious, it must be remembered that the spectra selected cannot, of course, represent the whole of a class Each class itself is sub-divided on a decimal scale —thus, B8 denotes a star eight-tenths of the way from B to A (generally written B_0 and A_0 respectively) —and when the whole series is considered the continuity of type is obvious The particular feature of the spectra selected by the Harvard observers as a criterion for distinction is the relative intensity of the most prominent lines Thus, the passage along the sequence of K spectra towards M is marked by a gradual appearance and intensification of the titanium oxide bands which appear at their greatest strength in the later divisions of class M Other slight differences, which we shall refer to presently, are noticeable in the spectra, but these are ignored in the classification a star is classified within class K or M by the prominence of the titanium oxide bands, and by very little else

Now, what are the salient features of this series of spectral classes ? Omitting the smaller classes, for lack of space, we will confine our attention to the main sequence B, A, F, G, K, M, since more than ninety-nine per cent of stellar spectra are included in these classes, we are losing very little in generality by thus restricting ourselves If we take up a purely chemical point of view, as the earliest observers did, we shall have merely to say that, in going from B to M, we find the most prominent substances represented in the spectra to change from helium to hydrogen, hydrogen to the metals (particularly calcium), and the metals to compounds (mainly titanium oxide) If, further, we assume, with most of the pioneers in this work, that all the substances present in a star's atmosphere must show their spectrum lines with intensities roughly proportional to the relative amounts of the substances there, we shall conclude that the earliest type stars (as stars at the beginning of the sequence are called) contain little but helium or hydrogen, while the late type stars contain a great variety of substances But, at the present time, fortunately, neither the purely chemical point of view nor the assumption we have mentioned is possible We must consider the physical conditions in the stellar atmospheres also, and it is necessary that we should digress for a moment in order to explain how a spectrum depends on the physical conditions of its production

When a substance—say, a piece of thallium, is made luminous in an electric arc, it gives a certain spectrum (*see* page 490) If the substance is used as the electrodes in a condensed electric spark, another spectrum is produced, which is only in part identical with the former one There are some lines common to both spectra, but the spark spectrum contains also some new lines, while some of the arc lines are weakened or disappear altogether The significance of this change was first pointed out by Lockyer He attached a special importance to the lines which were strengthened, or which appeared for the first time, in passing from the arc to the spark, and gave them the name of *enhanced* lines He attributed their existence to the effect of a higher temperature than that necessary to produce the ordinary arc lines, and he imagined a condition of temperature in which a substance would produce